2ND EDITION

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TEST GEAR VOL.2

PROJECTS INCLUDE:

- SWR/POWER METER
- AUDIO OSCILLATOR
- TRANSISTOR TESTER
- SOUND LEVEL METER
- AUDIO POWER METER
- TRUE RMS VOLTMETER
- RF SIGNAL GENERATOR
- CROSSHATCH GENERATOR
- AUDIO SPECTRUM ANALYSER
- 40V/5A LABORATORY SUPPLY
- DIGITAL TEMPERATURE METER
- VERSATILE LOGIC TEST PROBE
- FIELD STRENGTH POWER METER
- UP/DOWN PRESET TABLE COUNTER
- MICROWAVE OVEN LEAK DETECTOR
- LINEAR-SCALE CAPACITANCE METER

TEST GEAR VOL.2

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Editor: Roger Harrison

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The first edition of this book was published in October 1979. Several projects published in the original edition have been replaced, as components are known to be no longer available. Components specified should still be generally obtainable but it would be prudent to check the availability of any specialised parts before commencing construction. No responsibility for availability of components is accepted by the publisher or producer of this book.

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Whilst every effort has been made to ensure that all projects referred to in this edition will operate as indicated, efficiently and properly, no responsibility whatsoever is accepted in respect of the failure of the project to operate effectively or at all, whether due to any fault in design or otherwise, and no responsibility is accepted in respect of any injury or damage caused by any fault in the design of any such project aforesaid. The articles in this project aforesaid. The articles in this book were originally published in *Electronics Today International.*

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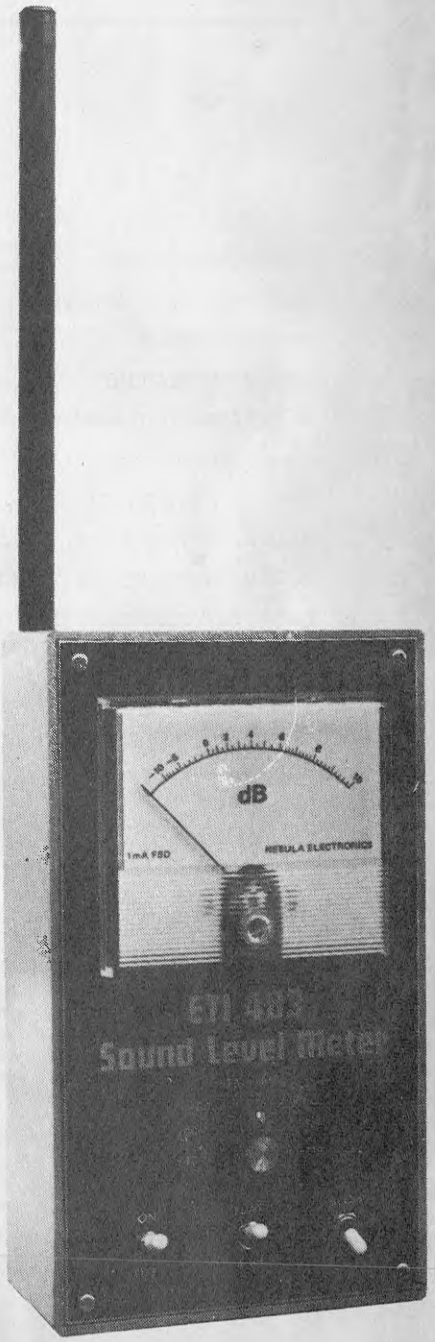
Sound-level meter

This sound level meter gives accurate results to allow noise levels to be monitored and controlled. An 'A' weight response is provided as well as the 'flat' mode.



THE PUBLIC TODAY is increasingly critical of excessive noise levels. Aircraft like the Concorde, for example, face opposition on grounds of noise levels while jet aircraft of around 1958 were just as noisy but then they were a great advance in science! Public awareness of noise has caused laws to be passed limiting the sound levels which can be produced without prosecution.

However, while it may be good to have a law to say the acoustic output of your party should not exceed 85 dB, how can you tell precisely what the actual level is! If the local constable is called the chances are he will not have a meter and will only be able to give his subjective assessment.

For this reason we have designed this project. It is not a super-duper do-all sound level meter but one which is economical yet gives meaningful results. The microphone used is relatively cheap (about $3.00), but is rugged and has a good frequency response. The microphone used in the B & K sound level meter is delicate and costs a small fortune !

There are many weighting networks used with sound level meters including ones which need a computer to calculate the results. We chose only the two most popular, the "A" weight and flat. The response of the "A" weight filter is given in Fig. 2.

SPECIFICATION – ETI 483

Sound level range	30dB to 120dB
Weighting networks	Flat or 'A' weight
Microphone	Electret
Power supply	9V dc @ 10mA

Construction

Assemble the PC board according to the overlay in Fig. 4. The rotary switch can be either of the two popular sizes and can be mounted either with tinned copper wires or by drilling large (3mm) holes in the PC board, through which the leads of the switch can be passed and soldered directly to the tracks. Check when assembling that the wiper contact is in the correct position.

Assemble the front panel and leave the leads to the switches and meter long enough to be able to hinge it forward, as the PC board is mounted in the base of the box. The microphone insert is mounted on the end of a length of aluminium tube well away from the box. This is to help prevent reflections from the box affecting the readings. We attached the microphone using a length of heat shrink tubing over the aluminium tubing.

Calibration

This is a little difficult as a known reference is needed or another sound level meter to match it against. Initially however the "flat" attenuator potentiometer must be adjusted. To do this a 1kHz audio tone or sine wave signal across R1 is needed. Select "A" weight and an appropriate range and note the reading. Switch to "flat" and adjust RV1 to give the same reading.

Calibration is performed by RV2 and is adjusted with a known audio signal.

When this unit was originally published, an LM301A was used for IC3. It was subsequently found that some LM301As caused non-linear readings. Replacing the LM301A with a CA3140 cures the non-linearity but on some devices the offset voltage prevents the needle settling on the lowest mark when in a quiet location and on the 110 dB range. If this is only slight, simply turn the meter zero adjust. However if not enough range is available, a trim potentiometer (10 k) connected between pins 1 and 5 on IC3 with the wiper connected to the 0V line will allow adjustment.

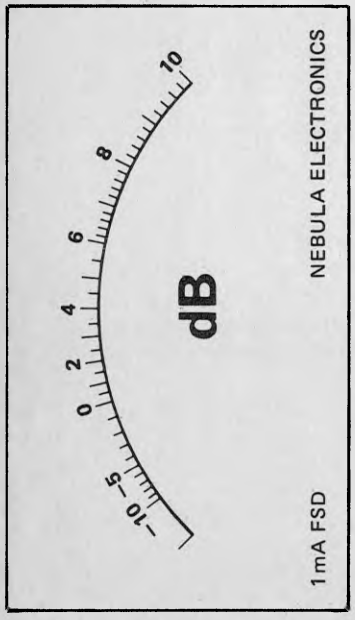
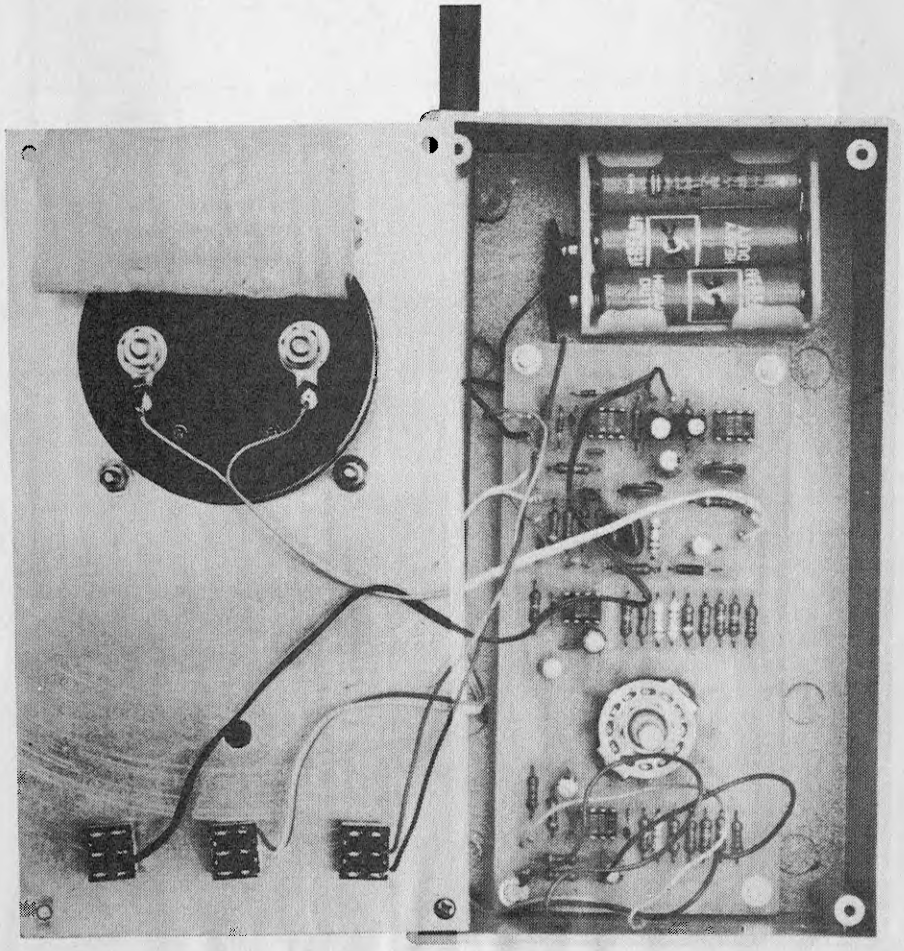


Fig. 2. The response of the 'A' weight filter.

Fig. 1. The meter scale shown full size.



An internal view of the unit.

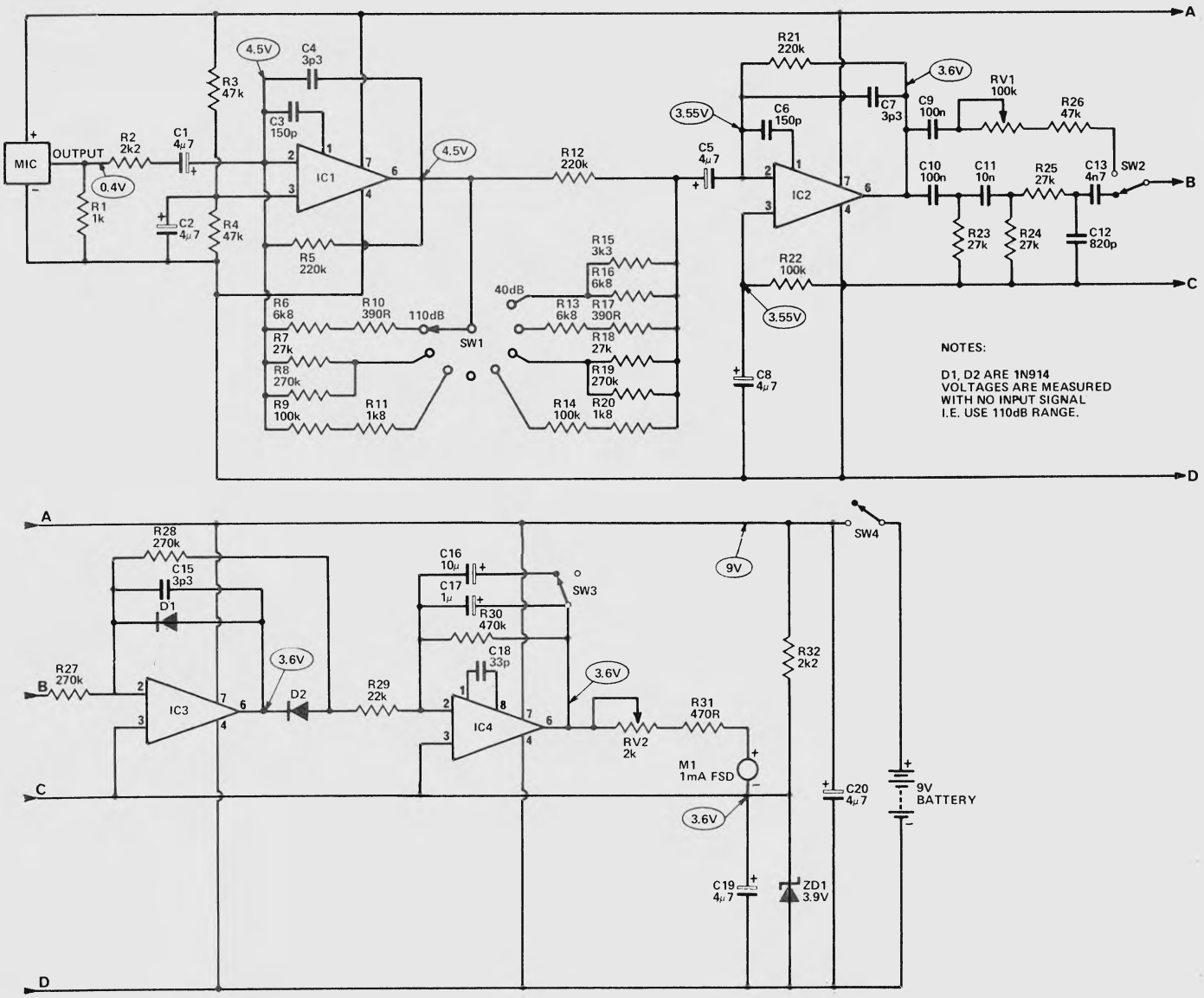


Fig. 3. The circuit diagram of the unit.

HOW IT WORKS – ETI 483

We have used an electret microphone insert which has the necessary FET preamp inside. As its output is a low level, especially in ambients around 40dB it is amplified by IC1 and IC2. The range switch SW1 is used to vary the gain of both ICs as shown below:

Range (dB)	Gain IC1 (dB)	Gain IC2 (dB)	Total Gain (dB)
+40	40	40	80
+50	40	30	70
+60	40	20	60
+70	40	10	50
+80	40	0	40
+90	30	0	30
+100	20	0	20
+110	10	0	10

The use of a switch as shown allows a single pole switch to control the gain of the two ICs while reducing the possibility of instability where gains of 80dB are involved.

The output of IC2 is filtered by the "A" weight network C10-C13, R23-R25 and R27. Switch SW2 selects either this "A" weighted output or the "flat" output via RV1, R25. The potentiometer RV1 is necessary to compensate for the loss of the filter network. Both networks should have the same loss at 1kHz.

IC3 is used to halfwave rectify the signal and IC4 integrates the signal to give the average level. Two values of integration capacitor are used to give the two response speeds.

The bias for the first IC is provided by R3 and R4 while the other three are biased by the voltage across ZD1. The meter is also biased to the zener voltage.

The printed circuit board for this project is reproduced on page 56.

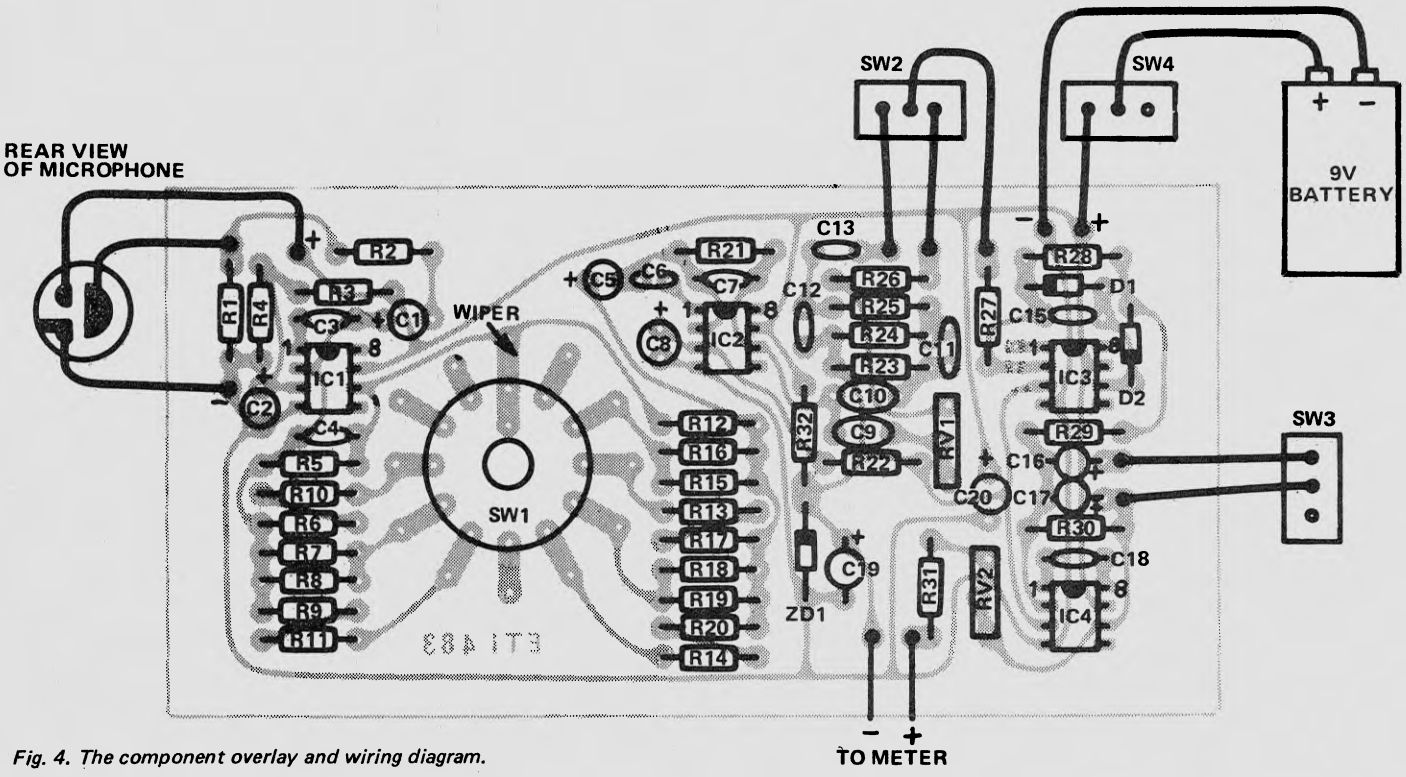


Fig. 4. The component overlay and wiring diagram.

PARTS LIST – ETI 483

Resistors all ½W 5%

R1 . . . . . 1k
R2 . . . . . 2k2
R3,4 . . . . . 47k
R5 . . . . . 220k
R6 . . . . . 6k8
R7 . . . . . 27k
R8 . . . . . 270k
R9 . . . . . 100k
R10. . . . . 390R
R11. . . . . 1k8
R12. . . . . 220k
R13. . . . . 6k8
R14. . . . . 100k
R15. . . . . 3k3
R16. . . . . 6k8
R17. . . . . 390R
R18. . . . . 27k
R19. . . . . 270k
R20. . . . . 1k8
R21. . . . . 220k
R22. . . . . 100k
R23–R25 . . 27k
R26. . . . . 47k
R27,28 . . . . 270k
R29. . . . . 22k
R30. . . . . 470k
R31. . . . . 470R
R32. . . . . 2k2

Potentiometers

RV1 . . . . . 100k trim
RV2 . . . . . 2k "

Capacitors

C1,2 . . . . . 4µ7 16V electro
C3. . . . . 150p ceramic
C4. . . . . 3p3 "
C5. . . . . 4µ7 16V electro
C6. . . . . 150p ceramic
C7. . . . . 3p3 "
C8. . . . . 4µ7 16V electro
C9,10. . . . . 100n polyester
C11. . . . . 10n "
C12. . . . . 820p ceramic
C13. . . . . 4n7 polyester
C15. . . . . 3p3 ceramic
C16. . . . . 10µ 16V electro
C17. . . . . 1µ0 16V "
C18. . . . . 33p ceramic
C19,20 . . . . 4µ7 16V electro

Semiconductors

IC1,2 . . . . . LM301A
IC3 . . . . . CA3140
IC4 . . . . . LM301A
D1,2 . . . . . 1N914
ZD1. . . . . 3.9V 300mW

Miscellaneous

PC board ETI 483
Microphone insert Tandy
Cat. 270-092
SWI single pole 11 position rotary
SW2–SW4 SPDT toggles
1mA meter
Plastic case
6xAA size battery holder

The Decibel (db)

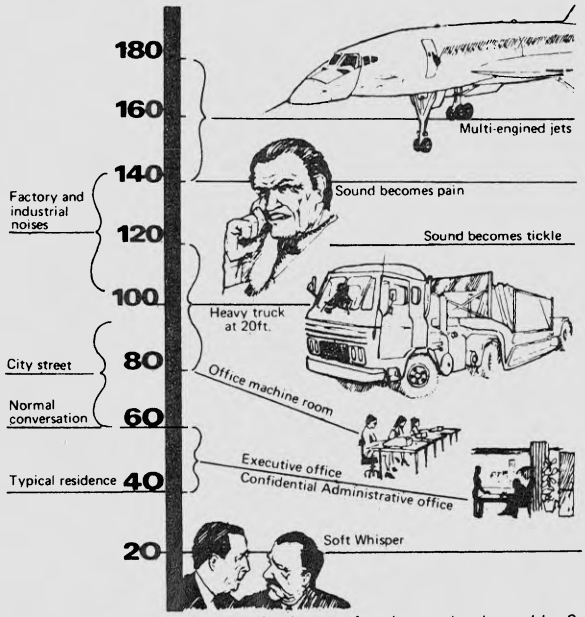
The ear can hear a sound power as low as 10^{-13} watt – this is a pressure of ·0002 dynes per cm². The ear drum moves an amount approx. equal to the diameter of a molecule of nitrogen. When sound is uncomfortably loud, the hearer "feels" a tickle, then pain in the ear; a power level of 1 watt. approx.

Engineers take the logarithm of the power ratio and call it the DECIBEL (db).

The db level is given by – db = 10 log 10 $\frac{Watts}{10^{-13}}$

The sound pressure level is = 20 log 10 $\frac{P(dynes)}{\cdot 0002}$

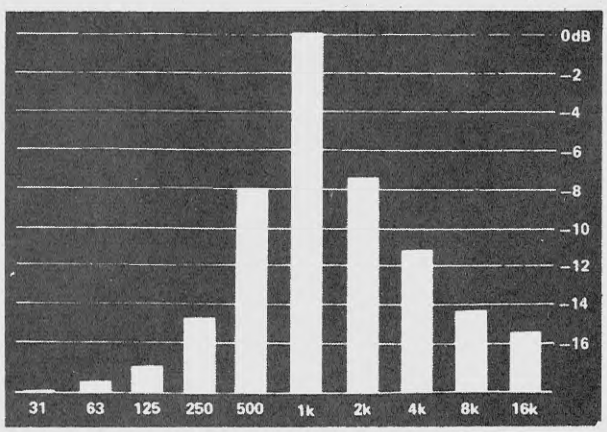
Typical Decibel levels encountered



- *For a sound to be perceptibly louder or softer, it must be changed by 3 decibels.*
- *A noise twice as loud or ½ as loud is a change of 10 decibels.*
- *A reduction in noise of a few decibels in the low noise region (administrative office) is not significant. The same change at high sound levels (office machine room) is significant.*

Audio spectrum analyser 1

Equalise systems for room acoustics accurately using this neat piece of 'test' gear.



AUDIO SPECTRUM ANALYSERS can be a valuable tool used in the setting up of a room acoustically with a graphic equalizer such as the ETI 485; to monitor programme material or just as a gimmick to please yourself and friends.

When setting up rooms pink noise is pumped into the room using an amplifier. A microphone is then used to monitor the sound and its output is the input to the analyser. Now by adjusting the graphic equalizer a flat response can (hopefully) be obtained.

SPECIFICATION – ETI 487

No. of bands	10
Frequencies	31, 63, 125, 250, 500, 1k, 2k, 4k, 8k, 16k
Filter characteristics	−12dB, one octave from nominal centre frequency
Display	CRO in XY mode
Input level	50mV – 10V
Input impedance	47k
Pink noise output	200mV
X output	±4 V approx
Y output	0V to 10V

Design Features

Spectrum analysis can be done by two main methods. The first is to have a tuneable filter which is swept across the band of interest. The output of the filter, when displayed on an oscilloscope, will be a frequency/amplitude graph of the input. While this gives a well-formatted and accurate display it is not "real time" in that if an event occurs at one frequency while the filter is sweeping elsewhere it will not be recorded. For this reason this method is used normally where the spectral content is constant and the sweep is only over a small percentage of total frequency (such as the output of a radio transmitter).

For real time analysis the frequency spectrum is broken into bands using bandpass filters and the output of each rectified. The output from these rectifiers can be displayed on a CRO as in this project or by columns of LEDs or similar methods. The number of bands and the dynamic range required determine the filters used. In this project where only about 20dB is required a single LC network is sufficient. Another unit we have built (not for a project) uses a 6 pole high pass filter followed by a 6 pole low pass one. This gives a flat response (∓ 1dB) over ∓ ½ octave and is 36dB down 1 octave away. However, it uses 6 op amps and 2% capacitors and resistors in each filter!

Our LED version of this project starts on page 26.

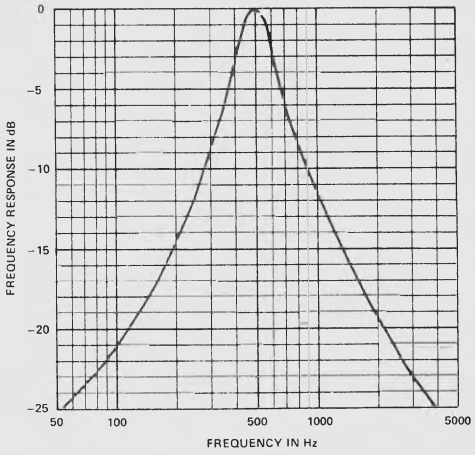


Fig. 1. The frequency response of the 500Hz filter. All other filters follow a similar curve.

HOW IT WORKS – ETI 487

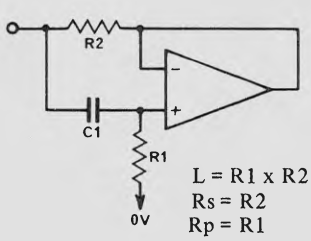
The unit can be broken into eight sections to help the explanation of how it works.

(a) Input amplifier
(b) Ten individual filters and rectifiers.
(c) Ten way analogue switch with decade counter.
(d) Staircase generator controlled by "c". (X output).
(e) Log converter.
(f) Ramp generator and comparator. (Y output)
(g) A pink noise generator.
(h) Power supply.

(a) The input amplifier has an input impedance of 220 k (set by R1) and a gain of 101 ((R3 + R2)/R2). The output of the amplifier drives all ten filters and Q1 and Q2 are used to buffer IC1 to give the drive capability required.

(b) The ten filter-rectifiers are identical except for component values and a bias resistor in the three lowest frequency filters, where tantalum capacitors are used in series. The filter is a parallel LC network which, with a series resistor, gives a band-pass filter.

As large value inductors are expensive we have used an active one using an operational amplifier, two resistors and a capacitor. The value of such a network is as follows:



$L = R1 \times R2 \times C1$ H
$Rs = R2$
$Rp = R1$

The frequency response of the networks is given in fig. 1.

The rectifier is a half wave type where the gain is variable from about 4 to 12. A diode from the output back to pin 2 keeps the op-amp in the linear region on the negative half cycle allowing operation up to the 16kHz of the top filter.

(c) The analogue switches IC23/1 – IC25/2 are controlled by IC22. This is a decade counter with 10 decoded outputs, each of which is high only for one clock period. As the analogue switches need a high to switch them on, only one will be selected at any one time.

(d) The output of the decade counter also controls the staircase generator IC28 with the weighting networks R58 – R72 giving equal steps of about 0.9 volts. Resistor R89 provides a bias current and the output of IC28 starts at about +4 volts and steps down in 0.9V steps to about -4.2 volts when the output switches back to +4 volts. This is used to drive the X input of the CRO. To add some width to the vertical lines, IC29/1 and IC29/2 form an oscillator of about 300 kHz and after filtering by R90 and C69 is coupled into the input of IC28 by R91.

(e) The output of the analogue switch is fed to the diode-resistor network (D21 - D26, R73 - R77) which gives a simple log conversion. This method is simple, needs no adjustments and is adequate for the purpose. As there is some loss in this network IC26 is used to provide a gain of three to recover this loss.

(f) The ramp generator is formed by the constant current (12μA) source and capacitor C71. The capacitor can be discharged by IC25/4 and the current source is controlled by IC24/3. The voltage out of the log converter (IC26) can vary between zero and +10 volts and this is compared to the ramp voltage by IC30. The output of IC30 controls the oscillator formed by IC29/3 and IC29/4. When the ramp voltage exceeds the voltage from IC26 the output of IC30 goes high allowing the oscillator to start. This immediately discharges C71 and switches off the current source which causes the output of IC30 to go low again after only about 2μs. Diode D27 ensures however that the oscillator acts as a monostable giving an output of about 6μs to ensure the capacitor C71 is completely discharged. The output of IC29/4 also clocks IC22 which selects the next input. If the input from IC26 is ever negative and C71 cannot be discharged to less than this voltage, IC29/3 and IC29/4 will oscillate continuously at about 100kHz clocking IC22 until it finds an input higher. This prevents possibility of lockup if the offset voltages of the op-amps all go the wrong way.

(g) White noise is generated by the zener action of Q3 which is reversed biased. It is amplified by Q4 to give 200 mV of white noise on its collector. White noise however has equal energy per unit bandwidth and what we need is pink noise which selects the next input. If the input bandwidth (i.e., equal energy per octave). To convert white to pink we need a filter at 3 db/octave. This is performed by IC27 with the RC networks providing the necessary curve.

(h) The power supply is a simple rectifier type with IC regulators to give stable supply voltages.

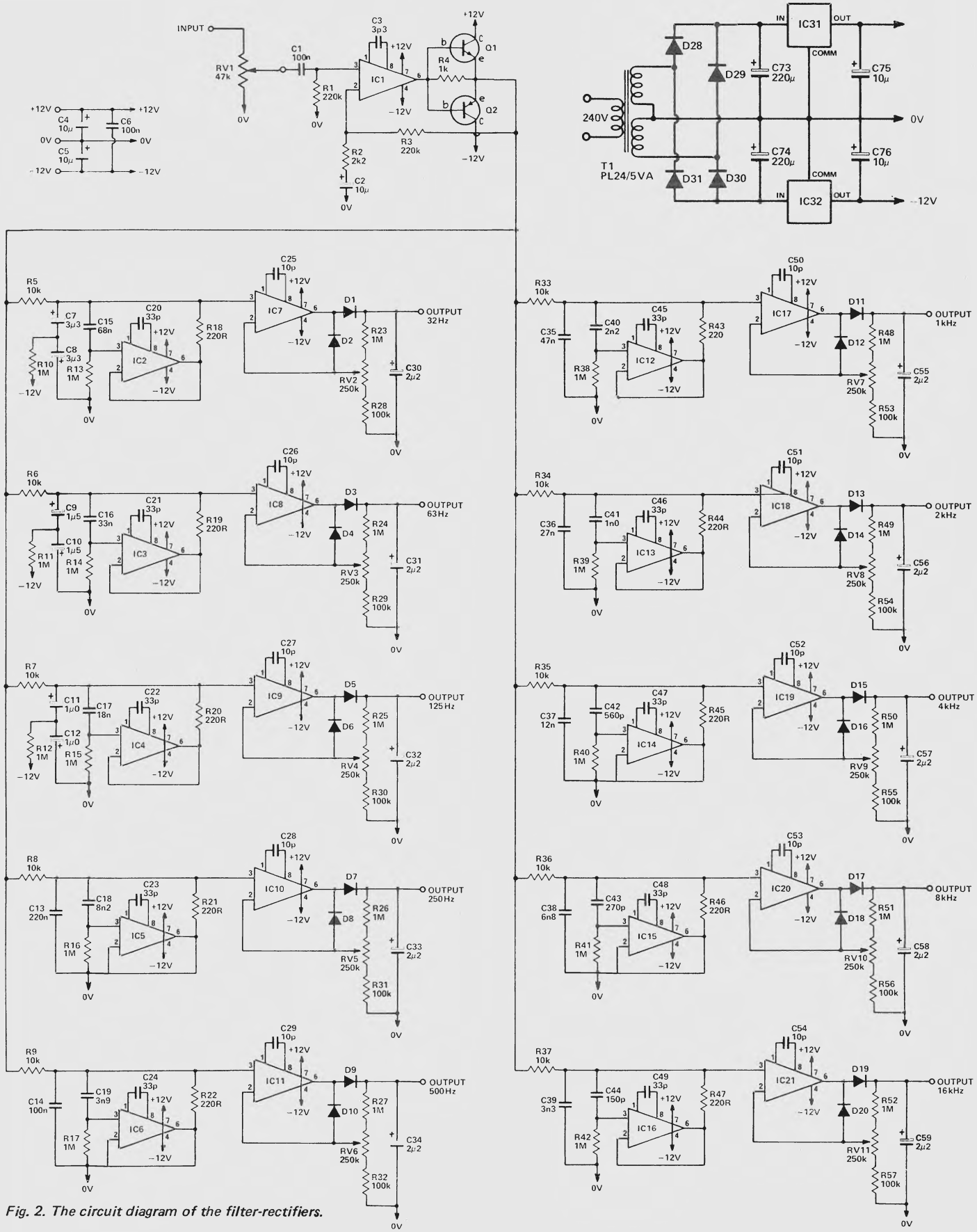


Fig. 2. The circuit diagram of the filter-rectifiers.

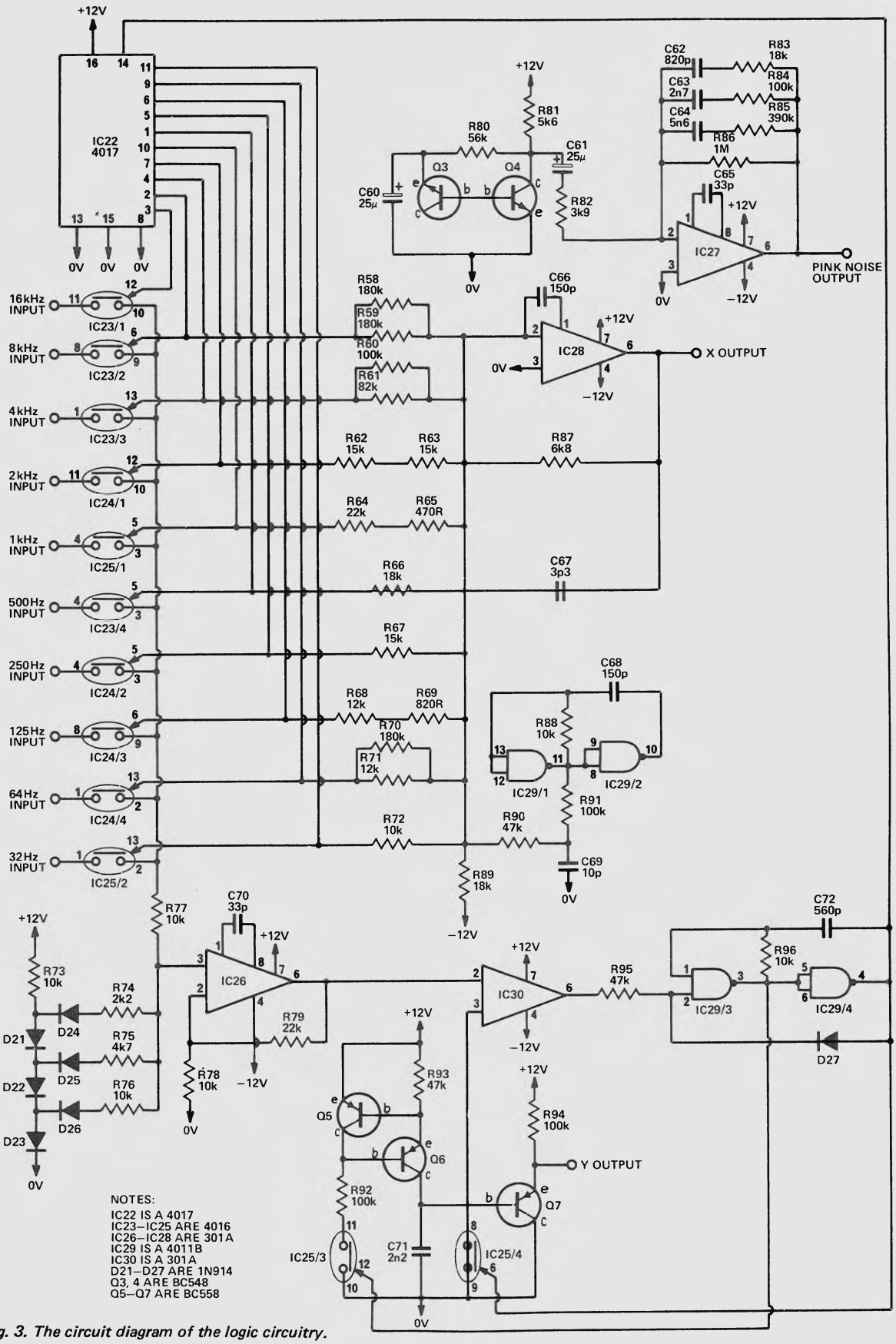
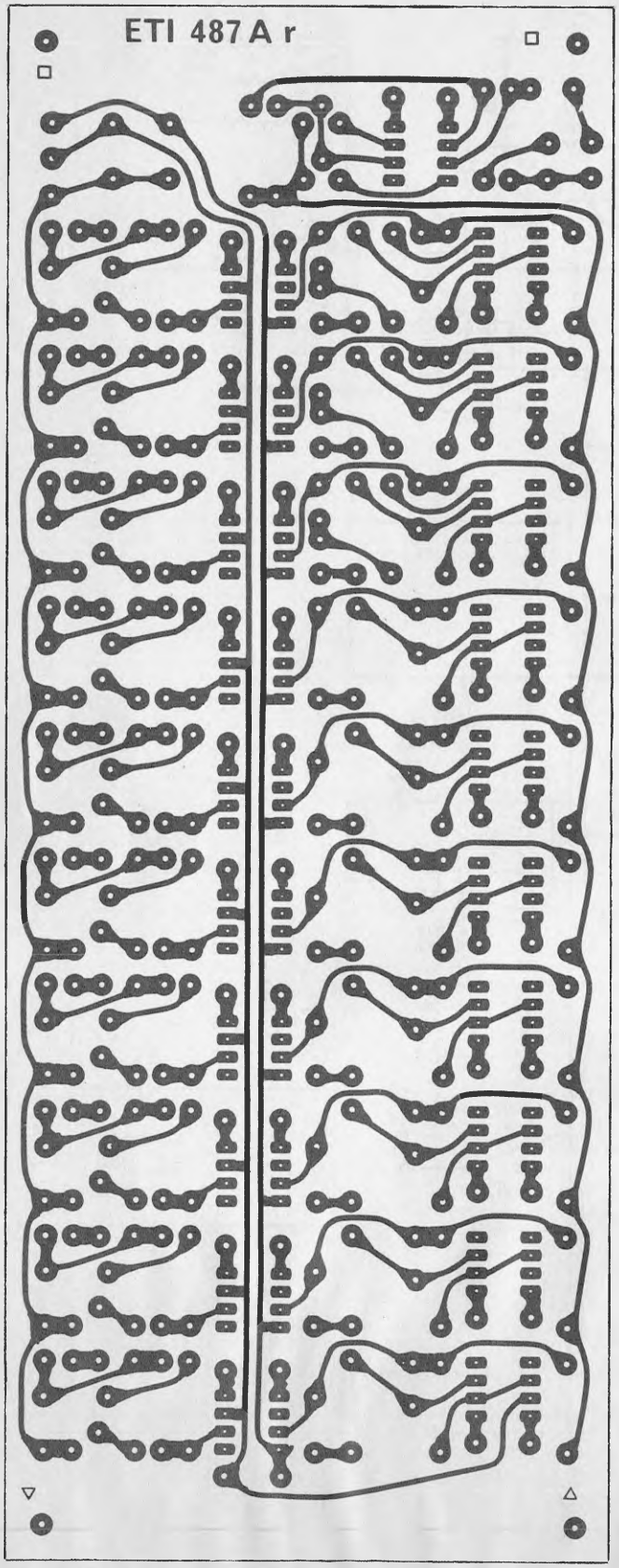


Fig. 3. The circuit diagram of the logic circuitry.

(description continues on page 14)



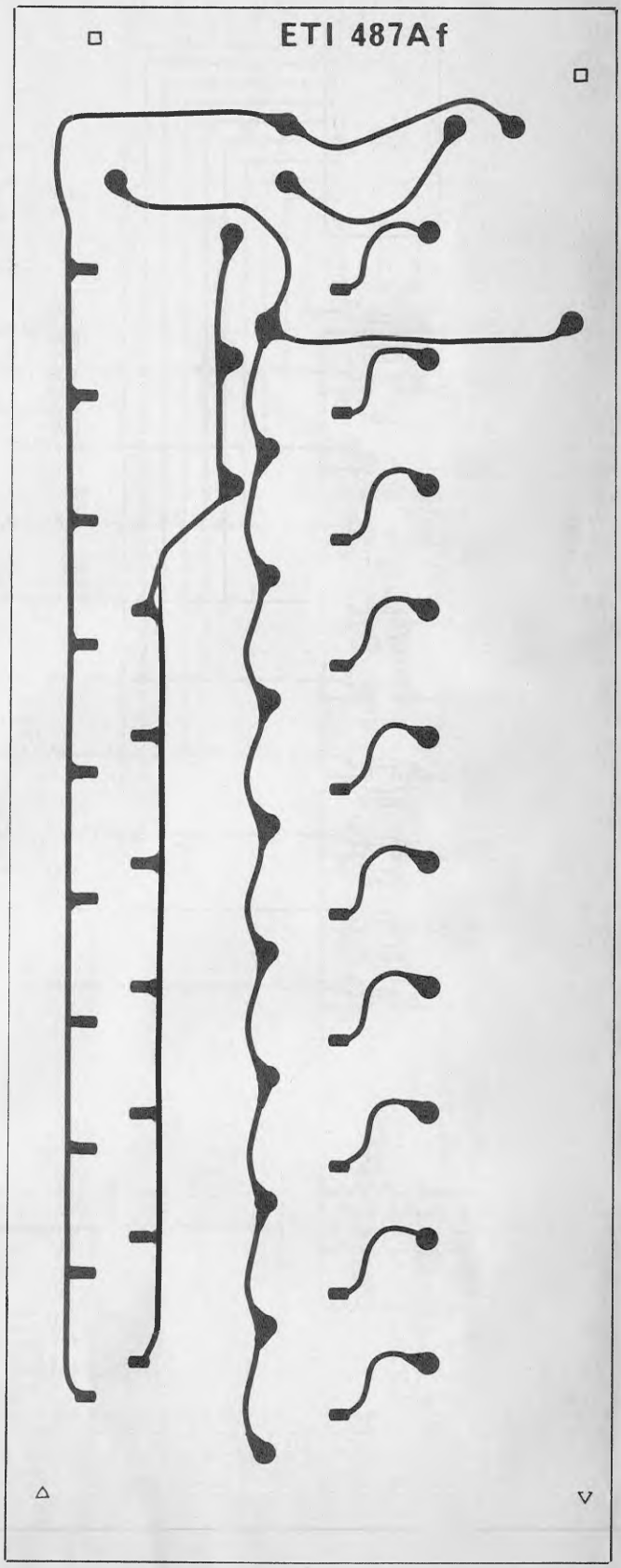


Fig. 4. Both sides of the ETI 487A board shown full size.

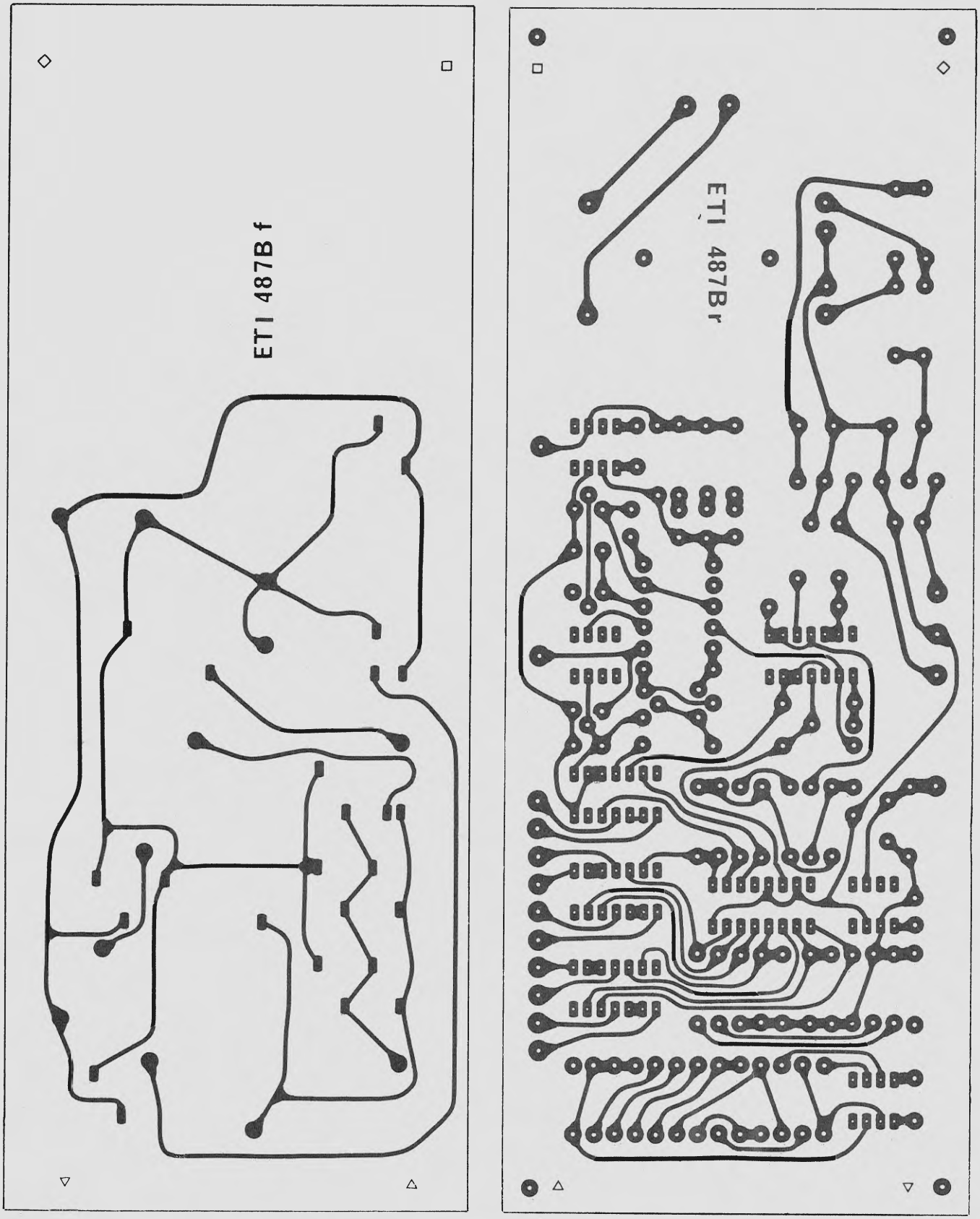


Fig. 9. Both sides of the ETI 487B board shown full size.

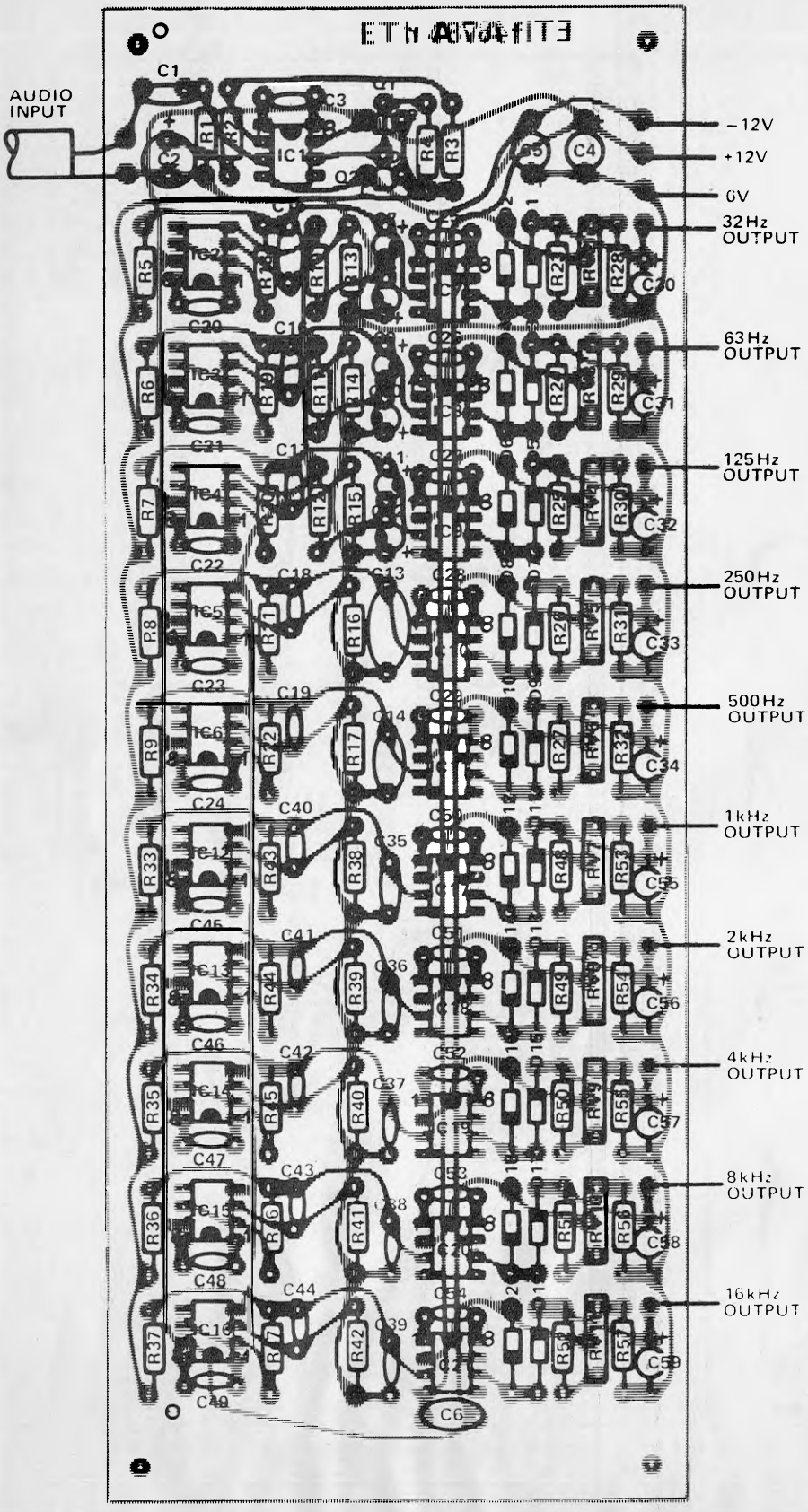


Fig. 5. The component overlay of the filter-rectifier board.

PARTS LIST – ETI 487

Resistors all ½W 5%

R1	220k
R2	2k2
R3	220k
R4	1k
R5–R9	10k
R10–R17	1M
R18–R22	220R
R23–R27	1M
R28–R32	100k
R33–R37	10k
R38–R42	1M
R43–R47	220R
R48–R52	1M
R53–R57	100k
R58,59	180k
R60	100k
R61	82k
R62,63	15k
R64	22k
R65	470R
R66	18k
R67	15k
R68	12k
R69	820R
R70	180k
R71	12k
R72,73	10k
R74	2k2
R75	4k7
R76–R78	10k
R79	22k
R80	56k
R81	5k6
R82	3k9
R83	18k
R84	100k
R85	390k
R86	1M
R87	6k8
R88	10k
R89	18k
R90	47k
R91,92	100k
R93	47k
R94	100k
R95	47k
R96	10k

Potentiometers

RV1	47k log rotary
RV2–RV11	250k trim

Capacitors

C1	100n polyester
C2	10µ 25V electro
C3	3p3 ceramic
C4,5	10µ 25V electro
C6	100n polyester
C7,8	3µ3 16V tantalum
C9,10	1µ5 16V "
C11,12	1µ0 16V "

Construction

Due to the complexity of the unit it is recommended that PC boards are used. These boards are assembled as per the overlay diagrams. Watch the orientation of all the ICs, diodes, capacitors, etc., when installing them. Note that as the board is not a plated through type that the tracks on the top side of the board must also be soldered to the components. This prevents the use of sockets for the ICs but they are not really worth the cost for low priced ICs

Capacitors continued

C13 . . . . . 220n polyester
C14 . . . . . 100n "
C15 . . . . . 68n "
C16 . . . . . 33n "
C17 . . . . . 18n "
C18 . . . . . 8n2 "
C19 . . . . . 3n9 "
C20–C24 . . . 33p ceramic
C25–C29 . . . 10p "
C30–C34 . . . 2µ2 25V electro
C35 . . . . . 47n polyester
C36 . . . . . 27n "
C37 . . . . . 12n "
C38 . . . . . 6n8 "
C39 . . . . . 3n3 "
C40 . . . . . 2n2 "
C41 . . . . . 1n0 "
C42 . . . . . 560p ceramic
C43 . . . . . 270p "
C44 . . . . . 150p "
C45–C49 . . . 33p "
C50–C54 . . . 10p "
C55–C59 . . . 2µ2 16V electro
C60,61 . . . . . 25µ 16V "
C62 . . . . . 820p ceramic
C63 . . . . . 2n7 polyester
C64 . . . . . 5n6 "
C65 . . . . . 33p ceramic
C66 . . . . . 150p "
C67 . . . . . 3p3 "
C68 . . . . . 150p "
C69 . . . . . 10p "
C70 . . . . . 33p "
C71 . . . . . 2n2 polyester
C72 . . . . . 560p ceramic
C73,74 . . . . . 220µ 25V electro
C75,76 . . . . . 10µ 25V "

Semiconductors

IC1–IC21 . . . LM301A
IC22 . . . . . 4017 (CMOS)
IC23–IC25 . . 4016 (CMOS)
IC26–IC28 . . LM301A
IC29 . . . . . 4011B (CMOS)
IC30 . . . . . LM301A
IC31 7812
IC32 7912
Q1 . . . . . BC548
Q2 . . . . . BC558
Q3,4 . . . . . BC548
Q5–Q7 . . . . . BC558
D1–D27 . . . 1N914
D28–D31 . . . 1N4001

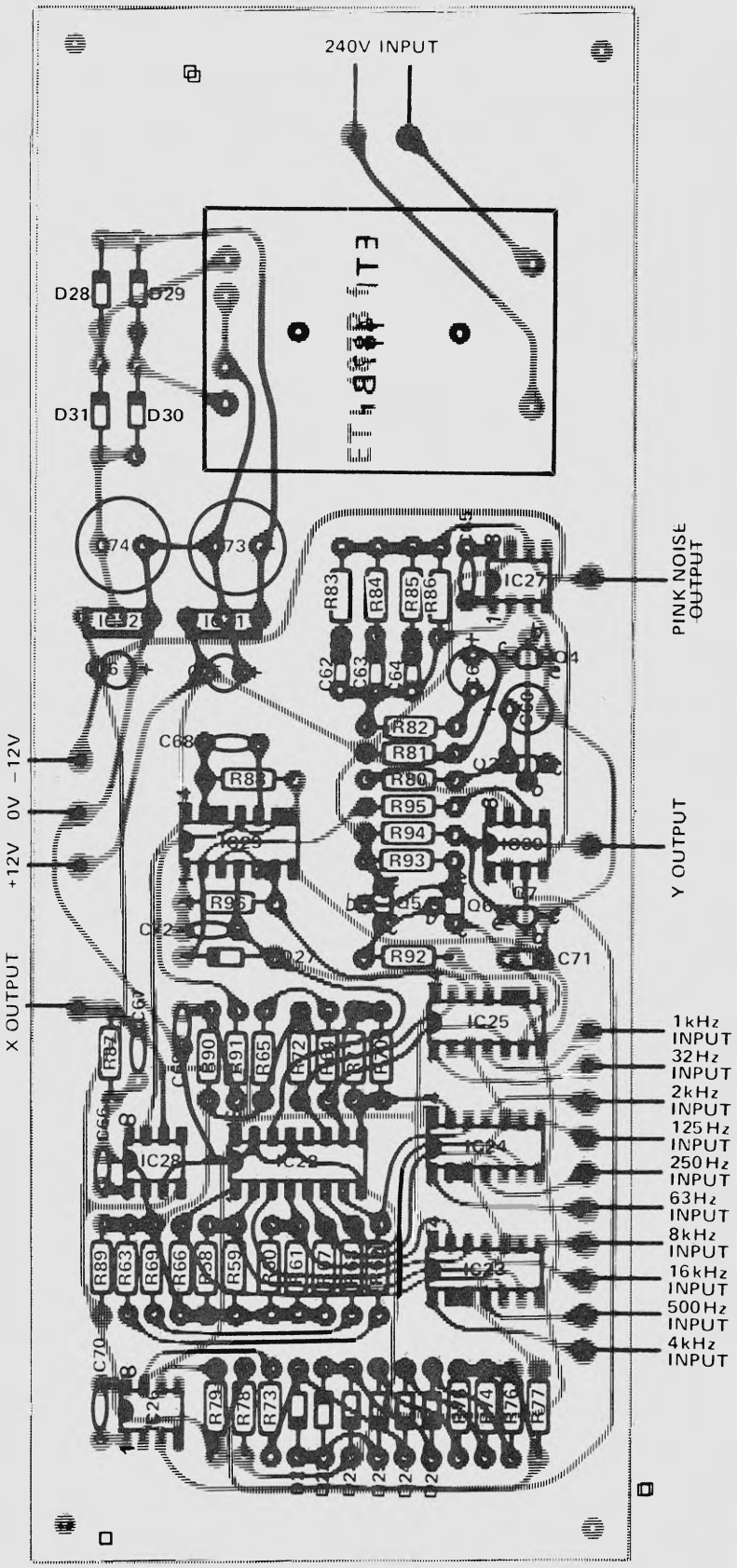
Miscellaneous

PC boards ETI 487A, 487B
Transformer PL24–5VA
Case to suit
3 core flex and plug
240V power switch
Input / output terminals to suit

as used.

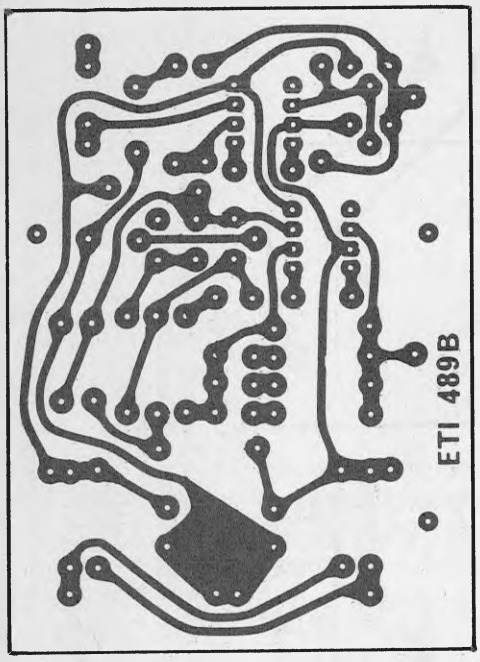
With the board 487A be very careful as there is 240V on the board. It is recommended that the wires be terminated directly to the board, without PC board pins, and that the 240V tracks on the underside of the board be coated with epoxy to prevent contact.

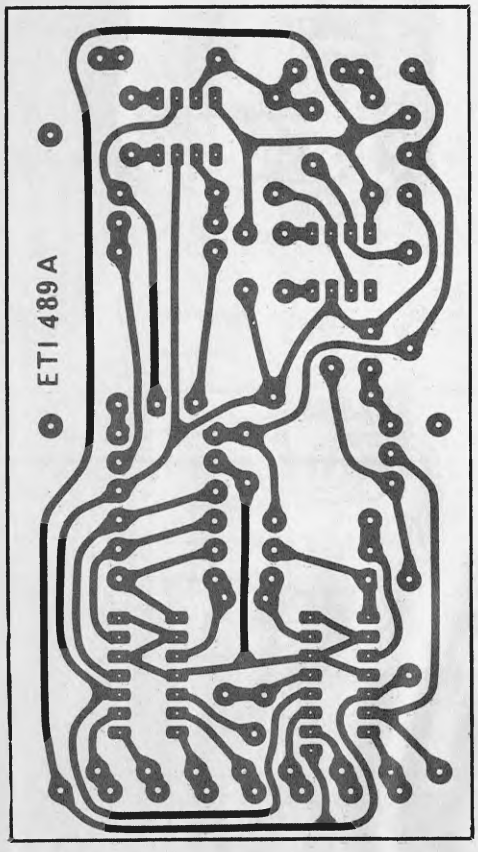
We mounted the unit into a home-made box as we did not have a commercial one on hand to suit.



Erratum: Capacitor C75 is shown positioned incorrectly. It should be turned through 180°. A link must also be made between the collector of Q2 and the end of R10 where the −12V track begins on the underside on the board.

AUDIO SPECTRUM
ANALYSER 2
(see page 26)
PC Boards 489A & B.





Alignment

This can be done using the pink noise generator or preferably with a sine wave oscillator.

Connect the unit to the oscilloscope switched into the X Y mode. With the unit switched on and a signal connected, adjust the X gain and shift to obtain a series of ten vertical bars across the screen. Increase the input signal until the columns will not get any higher. Adjust the Y gain and shift until the column is the height of the screen. Note that the scope should be dc coupled.

Now by sweeping the oscillator frequency it will be found that each column will come up in sequence. Adjust the frequency to peak the 16 kHz column. Now adjust RV11 to about 75% of its travel (wiper towards RV10) and then adjust the overall sensitivity control to give a column height of about 80%.

Now using the same amplitude adjust the signal generator frequency until the 8kHz column peaks and adjust RV10 to give the same height. Each of the filters should be adjusted in the same way. Note that due to component variations the actual peak of a filter may not exactly coincide with its nominal frequency. Also the 16kHz filter has the greatest loss which is the reason for starting with it near its maximum gain.

By taking the pink noise output to the input each column should be approximately the same height. Due to the nature of noise the top of the columns will jump up and down a little and this should be averaged out by the eye.

If an oscillator is not available the noise generator can be used and the potentiometers adjusted to give an even response. Also, if desired, a vertical dB scale can be made.

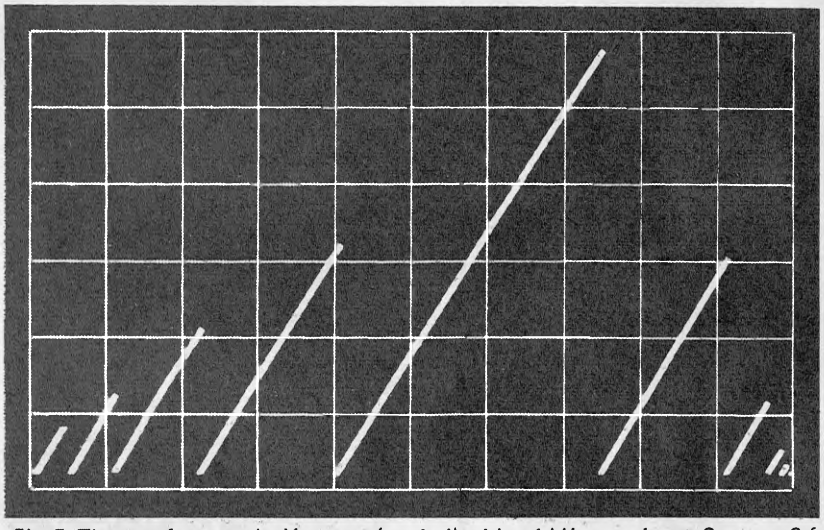


Fig. 7. The waveform on the Y output (vertical) with a 1 kHz tone input. See page 8 for the X-Y display. Note that the time between cycles varies with the height.

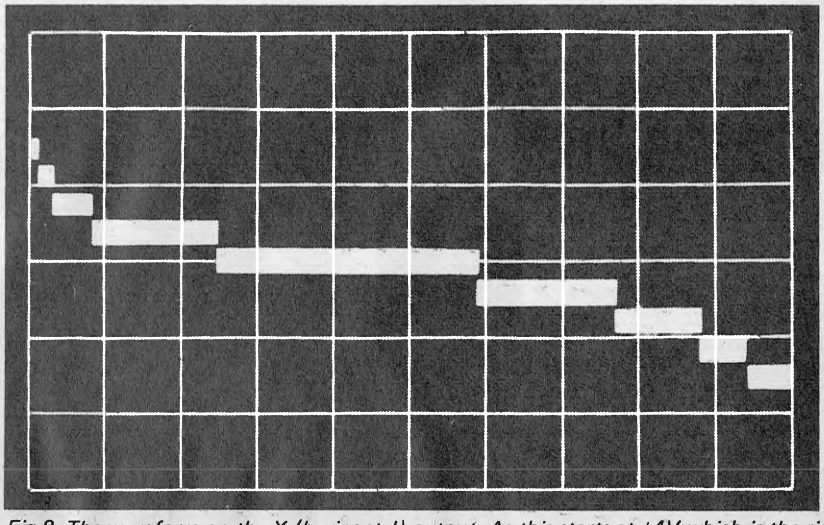


Fig.8. The waveform on the X (horizontal) output. As this starts at +4V which is the right hand side of the screen, the 16 kHz output is sampled first. Note that the time between steps corresponds to that in fig. 7.

Audio oscillator

Audio oscillator utilises new design in frequency meters, giving good accuracy and fast reading rates.

THE AUDIO OSCILLATOR is an almost essential piece of test equipment in any test lab be it professional or only the home workshop. Only the multimeter would rate more highly. We first published a simple sine-square oscillator way back in 1971 and this design is still very popular and selling well. We decided however to bring the design up to date adding a few improvements, and present it again.

Design Features

This oscillator started out as a redesign, mainly mechanical, of the earlier design. It then started to evolve as a voltage controlled sweep oscillator but when it became too complex we reverted to a simple Wein bridge oscillator.

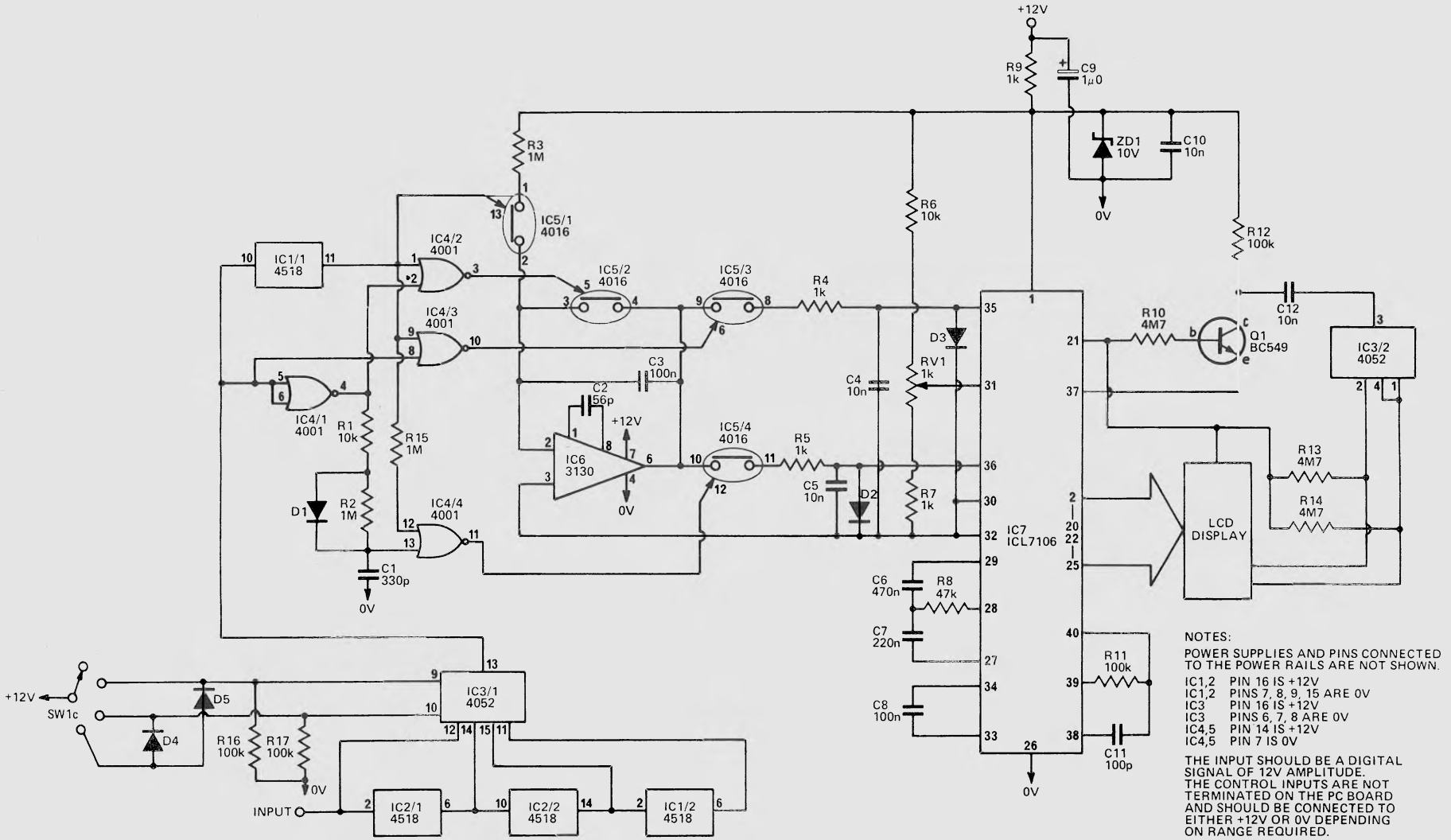
One major problem with all home made oscillators is that of scaling the frequency dial. This is not just a problem of positioning the knob but since normally available potentiometers have a tolerance of +/- 20%, the scale length will also vary. In commercial units the use of an expensive wire wound potentiometer solves most of the problems giving reasonably accurate scaling.

We then decided to build in a frequency meter, basing it on the ETI 533 display module. However the high power consumption (we wanted to allow battery operation) and the poor resolution, especially at low frequency, prompted the design of a completely new frequency meter.

This uses what is literally an analogue computer to convert a period measurement into frequency with some digital electronics controlling it and displaying the results. We based this on the Intersil ICL7106 module which, due to its liquid

Continued on page 20.

Front view of the audio oscillator. Note that this is an early prototype and the 3V range has been deleted.



NOTES:

POWER SUPPLIES AND PINS CONNECTED TO THE POWER RAILS ARE NOT SHOWN.

IC1,2	PIN 16 IS +12V
IC1,2	PINS 7, 8, 9, 15 ARE 0V
IC3	PIN 16 IS +12V
IC3	PINS 6, 7, 8 ARE 0V
IC4,5	PIN 14 IS +12V
IC4,5	PIN 7 IS 0V

THE INPUT SHOULD BE A DIGITAL SIGNAL OF 12V AMPLITUDE. THE CONTROL INPUTS ARE NOT TERMINATED ON THE PC BOARD AND SHOULD BE CONNECTED TO EITHER +12V OR 0V DEPENDING ON RANGE REQUIRED.

Fig. 1. The circuit diagram of the frequency meter section.

HOW IT WORKS - ETI 137

Oscillator

The oscillator is the conventional Wein bridge type with a differenial amplifier made up by Q1-Q5. Gain stabilization is done by the thermistor TH1. This type of circuit oscillates at the frequency where the impedance of the capacitors equals the resistors in the Wein bridge arms. With this feedback network the attenuation does not vary greatly like that of a twin tee but the phase shift does. The result is a sine wave oscillator with low distortion.

For frequency variation a two gang potentiometer is used to give a 20/1 continuous variation with switched capacitors giving four ranges each a decade apart.

The sine wave output is turned into a square wave by IC1 with the amplitude stabilized by D3-D6.

Frequency Meter

This section works by generating a voltage proportional to the period of one cycle and using this as the reference voltage for the Intersil voltmeter IC with a fixed voltage on the normal input. This gives the inverse function of normal operation and the display therefore is frequency.

To generate the reference voltage we use an integrator (IC6) which is controlled by IC5. Operation is as follows. Initially C3 is discharged and for one cycle of the input signal IC5/1 turns on. As the module provides a stable voltage between pin 1 and pin 32 of about 2.8V the output of IC6 will fall linearly with time and as IC5/1 is on for exactly one cycle the voltage change will be proportional to that period.

After IC5/1 turns off the output of IC6 will stay fixed. IC5/3 is then turned on and C4 will charge to that voltage. After half a cycle IC5/3 will turn off leaving C4 at that voltage and IC5/2 will turn on. This discharges C3 to zero volts. After a short delay to allow C3 to discharge IC5/4 is turned on transferring that voltage level onto C5. After a total of two cycles the process recommences. The voltage difference between the two capacitors is therefore the voltage *change*, (proportional to frequency) thus eliminating any offset errors in IC6. The pulses which control IC5 are derived from IC1/1 and IC4.

A reference voltage less than half the input voltage will result in the ICL7106 counting past 2000 (over ranging). The two inputs must also lie within the supply rails (less 1.5V). This limits the range of the instrument from 5 Hz to 200 Hz. For the higher frequency ranges, three decade dividers are provided and the necessary output selected by IC3. The correct decimal point is also selected by the other half of this IC.

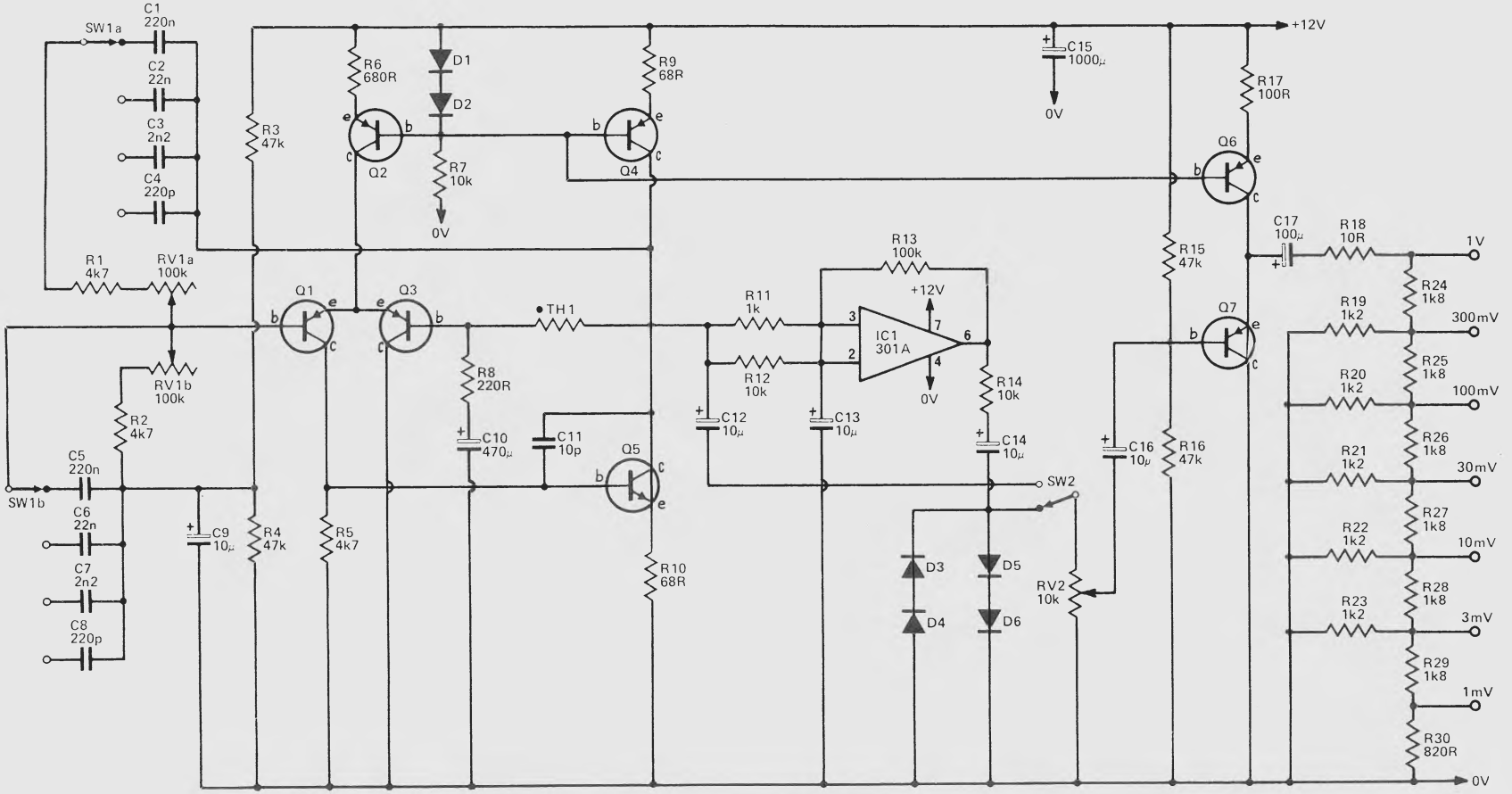


Fig. 2. The circuit diagram of the oscillator section.

crystal display, features low power consumption. Due to the method of conversion from period to frequency the range is limited from about 50 to 1999 counts and therefore automatic range selection is used. As the oscillator itself has less range than this, this limitation is no problem.

To simplify wiring we initially used CMOS analogue switches to select the range changing capacitors in the oscillator but this unfortunately increased the second harmonic distortion when the supply voltage dropped below 12 volts. This is due to the non-linearity of the "on" resistance when the input voltage changes. We therefore reverted to the good old mechanical switch!

Construction

Assemble the frequency counter board first, following the overlay provided. As this board is mounted very close to the front panel (only the height of the LCD) the capacitors should have leads long enough to allow them to be laid on their side on top of the resistors, etc. Also the CA3130 and the transistor will have to be mounted close to the board. While it is not essential that a socket be used (we didn't) for the LCD, one is recommended and although the Molex pins provided in the evaluation kit are not the best, they are available. Be very careful with the display as it is glass and therefore fairly fragile.

The oscillator board can now be assembled following its overlay diagram. The thermistor should be tied down using a loop of tinned copper wire and pc pins should be used on all external wire terminating points. Cut all leads short on the back of the pc boards as the two are mounted back-back with only 6 mm spacing.

We built the units into a large zippy box with all the components mounted on the front panel. The pc boards are secured by four 6BA c/s screws through the aluminium but hidden by the Scotchcal front panel used. The frequency meter board is spaced using 6BA nuts to give just enough clearance for the display and is held in place using 6.4mm long tapped spacers. Check that the spacers do not touch any tracks on the pc board and if so add pieces of insulation material under them.

The switches and potentiometers can now be mounted on the front panel and the wiring from the frequency counter board to the range switch done. Add wires from the two power connections and the input for later connection to the oscillator board.

Continued on page 22.

SPECIFICATION – ETI 137

Oscillator section	
Ranges	10.0 – 100.0Hz 100 – 1000Hz 1.00 – 10.00kHz 10.0 – 100.0kHz
Outputs available	sine or square
Output level	1V maximium continuously variable plus 10dB steps down to 1mV
Output impedance	nominally 600 ohms
Sine wave distortion	<0.1%
Square wave risetime	200ns
Frequency meter section	
Number of digits	3½
Display	LCD
Reading rate	5 per second
Resolution	0.1Hz on lowest range
Mode	Period measurment computed to read frequency
General	
Power consumpion	26mA @ 12V dc
Battery life	
Ni Cads	20 hours
Pencells (red)	30 hours
Pencells (alkaline)	50 hours

Printed circuit boards – page 58.

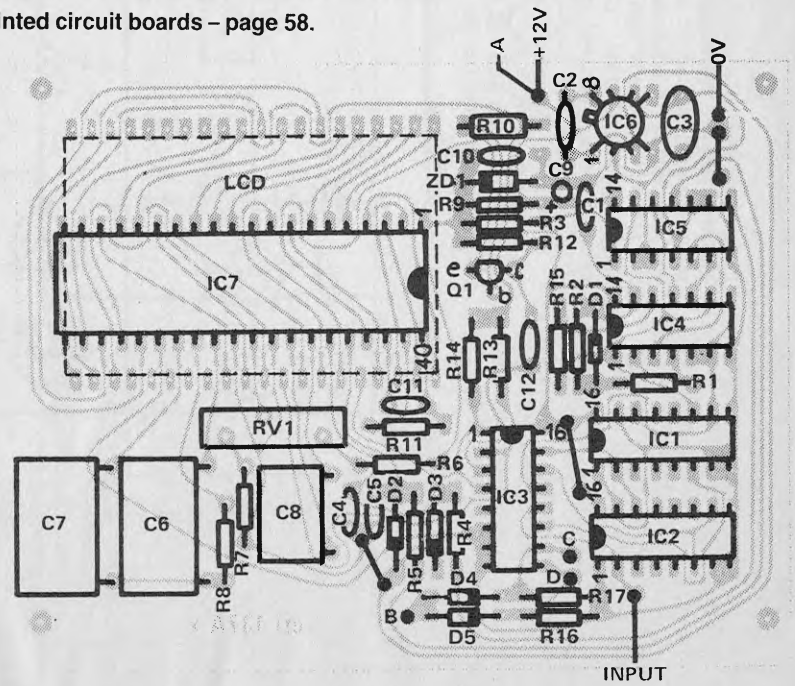


Fig. 3. Component overlay of the frequency meter board. Insert the LCD such that the +1 digit is on the left.

PARTS LIST – ETI 137

General
Plastic box UB
1 One pole 12 position rotary switch
1 Three pole 4 position rotary switch
2 STDP toggle switches
4 knobs to suit
12V battery (8xdry cell or 10xNicads)
External power socket
Scotchcal front panel
Wire, screws etc.

Frequency Counter Board – ETI 137A

Resistors all ¼W 5%
R1 . . . . . 10k
R2,3 . . . . . 1M
R4,5 . . . . . 1k
R6 . . . . . 10k
R7 . . . . . 1k
* R8 . . . . . 47k
R9 . . . . . 1k
R10. . . . . 4M7
* R11. . . . . 100k
R12. . . . . 100k
R13,14 . . . . 4M7
R15. . . . . 1M
R16,17 . . . . 100k

Potentiometer
* RV1 . . . . . 1k ten turn trim

Capacitors
C1. . . . . 330p ceramic
C2. . . . . 56p ceramic
C3. . . . . 100n polyester
C4,5 . . . . . 10n polyester
* C6. . . . . 470n polyester
* C7. . . . . 220n polyester
* C8. . . . . 100n polyester
C9. . . . . 1µ0 35V tantalum
C10. . . . . 10n polyester
* C11. . . . . 100p ceramic
C12. . . . . 10n polyester

Semiconductors
IC1,2 . . . . . 4518 (CMOS)
IC3 . . . . . 4052 (CMOS)
IC4 . . . . . 4001 (CMOS)
IC5 . . . . . 4016 (CMOS)
IC6 . . . . . CA3130
* IC7 . . . . . ICL7106
Q1 . . . . . BC549
D1–D5. . . . 1N914
ZD1. . . . . 10V 300mW Zener

Miscellaneous
PCB ETI 137A
* LCD display

* These parts are provided in the Intersil ICL7106 Evaluation Kit.

Oscillator Board – ETI 137B

Resistors all ½W 5%
R1,2 . . . . . 4k7
R3,4 . . . . . 47k
R5 . . . . . 4k7
R6 . . . . . 680R
R7 . . . . . 10k
R8 . . . . . 220R
R9,10. . . . . 68R
R11. . . . . 1k
R12. . . . . 10k
R13. . . . . 100k
R14. . . . . 10k
R15,16 . . . . 47k
R17. . . . . 100R
R18. . . . . 10R
R19–R23 . . 1k2
R24–R29 . . 1k8
R30. . . . . 820R

Thermistor
TH1. . . . . type R53

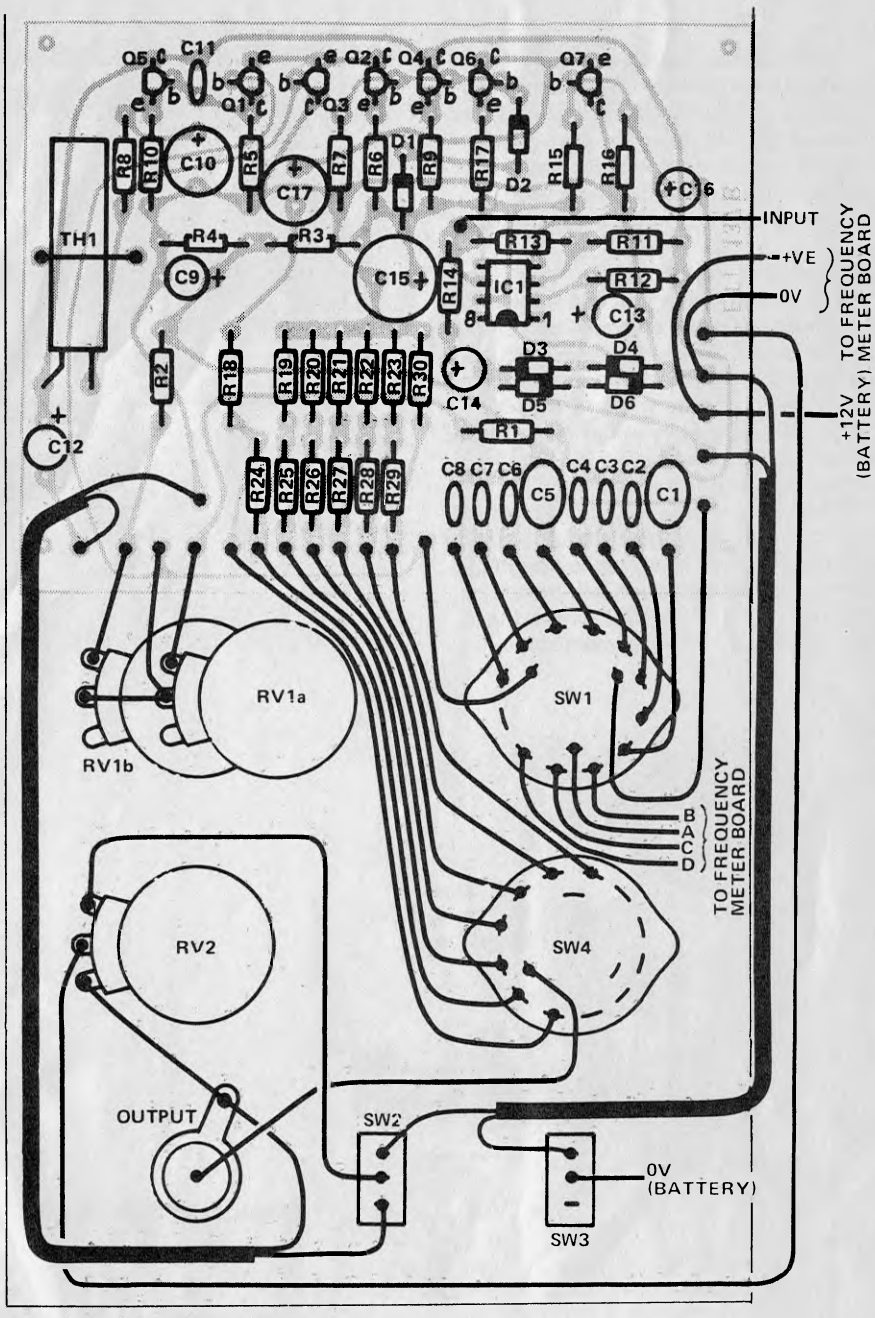

Q5 C11 Q1 Q2 Q3 Q4 Q6 Q7
R8 R10 C10 R5 C17 R7 R6 D1 R9 R17 D2 R15 R16 C16
TH1 R4 R3 C9 C15 R14 IC1 R13 R11 R12 C13
R2 R18 R19 R20 R21 R22 R23 R30 C14 D3 D4 D5 D6
C12 R1
R24 R25 R26 R27 R28 R29
C8 C7 C6 C5 C4 C3 C2 C1
RV1a RV1b SW1
RV2 SW4
OUTPUT SW2 SW3
0V (BATTERY)
B A C D
TO FREQUENCY METER BOARD
INPUT +VE 0V +12V (BATTERY)
TO FREQUENCY METER BOARD

Fig. 4. The component overlay of the oscillator board and the wiring of the front panel.

Potentiometers
* RV1 . . . . . 100k dual rotary
RV2 . . . . . 10k lin rotary

Capacitors
C1. . . . . 220n polyester
C2. . . . . 22n polyester
C3. . . . . 2n2 polyester
C4. . . . . 220p ceramic
C5. . . . . 220n polyester
C6. . . . . 22n polyester
C7. . . . . 2n2 polyester
C8. . . . . 220p ceramic
C9. . . . . 10µ 25V electro
C10. . . . . 470µ 25V Electro
C11. . . . . 10p ceramic
C12–C14 . . 10µ 25V electro
C15. . . . . 1000µ 16V electro
C16. . . . . 10µ 25V electro
C17. . . . . 100µ 25V electro

Semiconductors
IC1 . . . . . 301A
Q1–Q4. . . . BC559
Q5 . . . . . BC549
Q6,7 . . . . . BC559
D1–D6. . . . 1N914

Miscellaneous
PCB ETI 137B

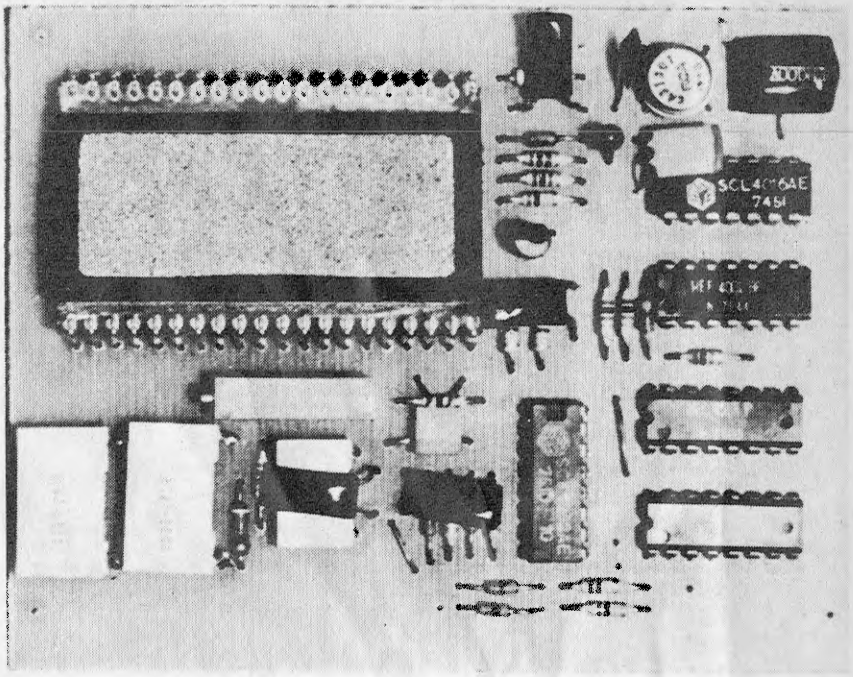
* RV1 – the preferred curve giving best resolution is antilog. If reverse rotation is acceptable log is as good. Otherwise use a linear curve.

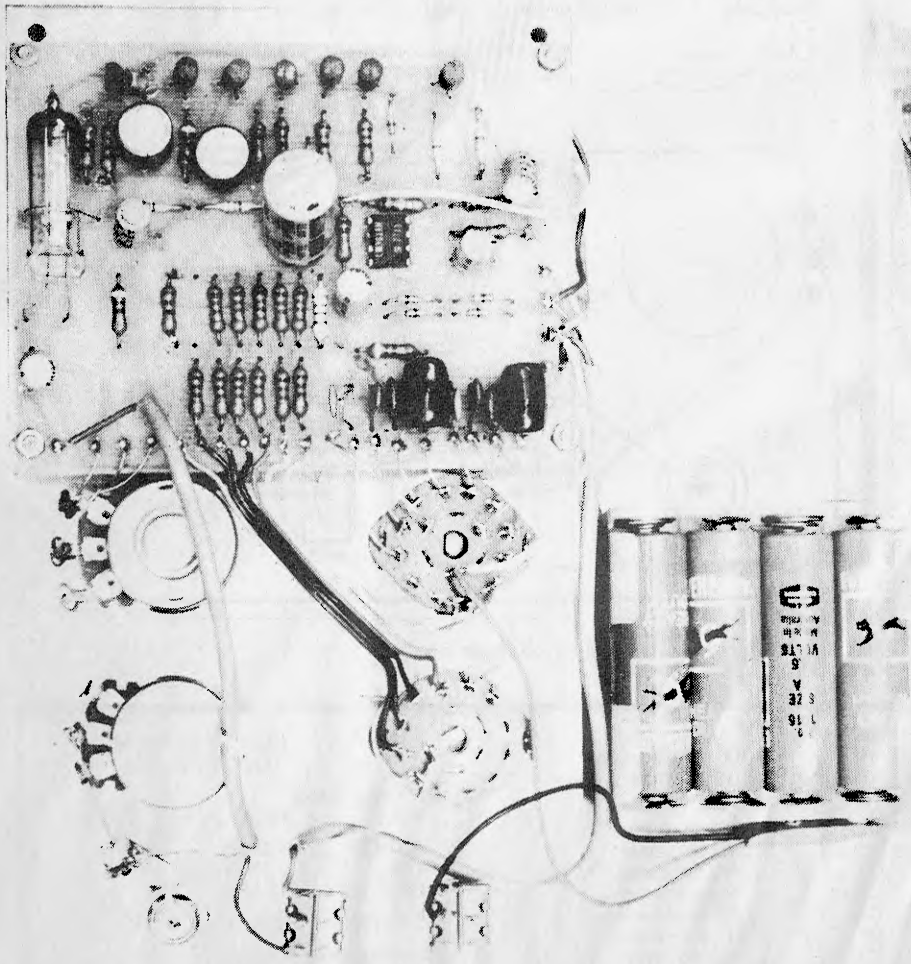
The oscillator board can now be mounted onto the back of the frequency meter board ensuring that no leads short between the two boards. Also check that the spacers do not touch any tracks on the oscillator board. The wiring of the front panel can now be completed.

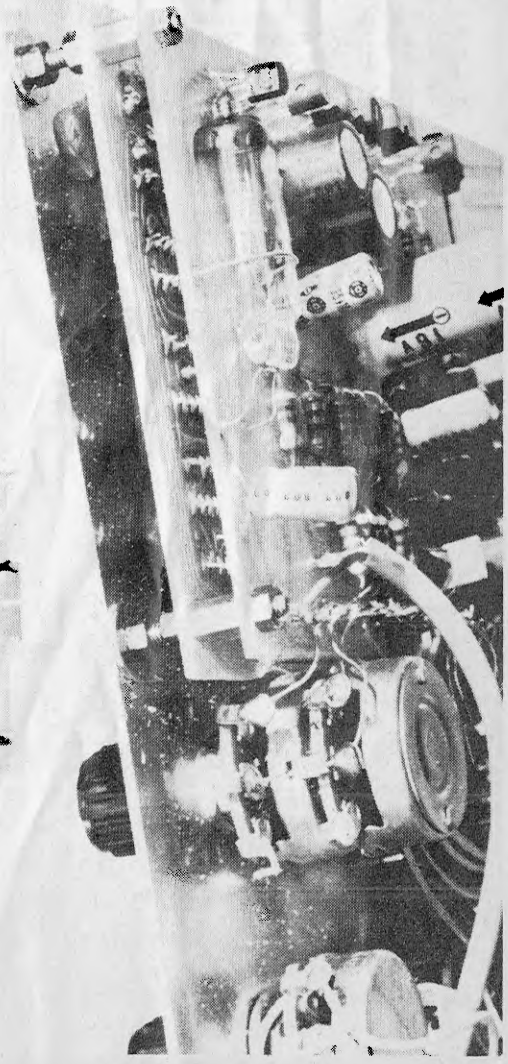
Checking and Adjustment

Switch on and check that the frequency meter and oscillator are working. Monitor the output of the oscillator with an accurate frequency counter and adjust the oscillator to the top end of one range. The frequency meter can now be calibrated by means of the 10 turn potentiometer on that board.

Check that the display range changes correctly and that the decimal point also moves. Each range while nominally having a 10-100 variation will be adjustable from about 7 to 150. Check the attenuator has 10 dB between steps.







Digital panel meter

This simple, economical yet highly accurate voltmeter uses a large liquid crystal display for easy reading and low power consumpion. It will be the basis of future projects as well as being a useful meter in its own right.

WE INITIALLY purchased a number of Intersil evaluation kits for our own use but soon realised that while they were very good electronically, the physical layout wasn't too hot. We therefore redesigned the PC board, reducing the size dramatically, adding the decimal point drive circuitry and some dropping resistors and zener diodes to allow the board to run from a dual power supply of +/– 5V or more (e.g. with op-amps). This resulted in a very useful device which we decided to run as a project. While it is basically a panel meter suitable for DC voltages and current (with a shunt) it will be the display module for several future projects.

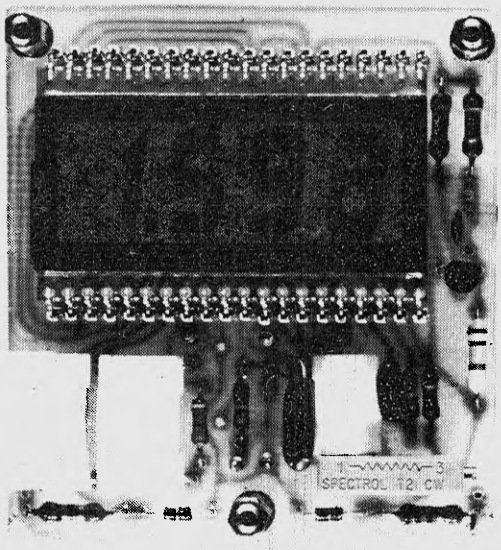
Construction

To save on real estate, the main IC is mounted under the display. We used the Molex connectors supplied with the evaluation kit for the display and soldered the IC directly into the board. If you want to mount the IC in a socket a low profile type should be used, with a high one for the display. As a socket is not available for the display a standard 40 pin one can be cut up to fit.

However before fitting either the display sockets or the IC, fit all the other components first. The overlay in fig. 3 shows the positioning of the components. Most of the components come with the evaluation kit. The large capacitors are laid on their side to minimise height.

When fitting the IC solder pins 1 and 26 first (the power supply pins) so that the protection diodes on the inputs can operate, thus preventing damage by static electricity. It is necessary that a small tipped iron and fine solder be used to prevent bridging tracks. The Molex sockets can now be fitted in two strips of 20 with the top connecting pieces being broken off using long nosed pliers after they are soldered in.

As there are no polarity marks on the display it is necessary to hold it at an angle to the light and look for the outline of the digits. The full format of the display is shown in fig. 2. In this unit the arrow, semicolon and the vertical part of the + sign are not used.



SPECIFICATION – ETI 135

Full scale reading	200mV
Resolution	100μV
Accuracy	$<$1 digit
Display	3½ digit LCD
Input impedance	$>10^{12}$ ohms
Input bias current	$\approx$2 pA
Polarity	automatic
Conversion method	dual slope
Reference	internal $\pm$ 100ppm
Power supply	$\pm$5V to $\pm$ 15V dc 1mA @ $\pm$5V

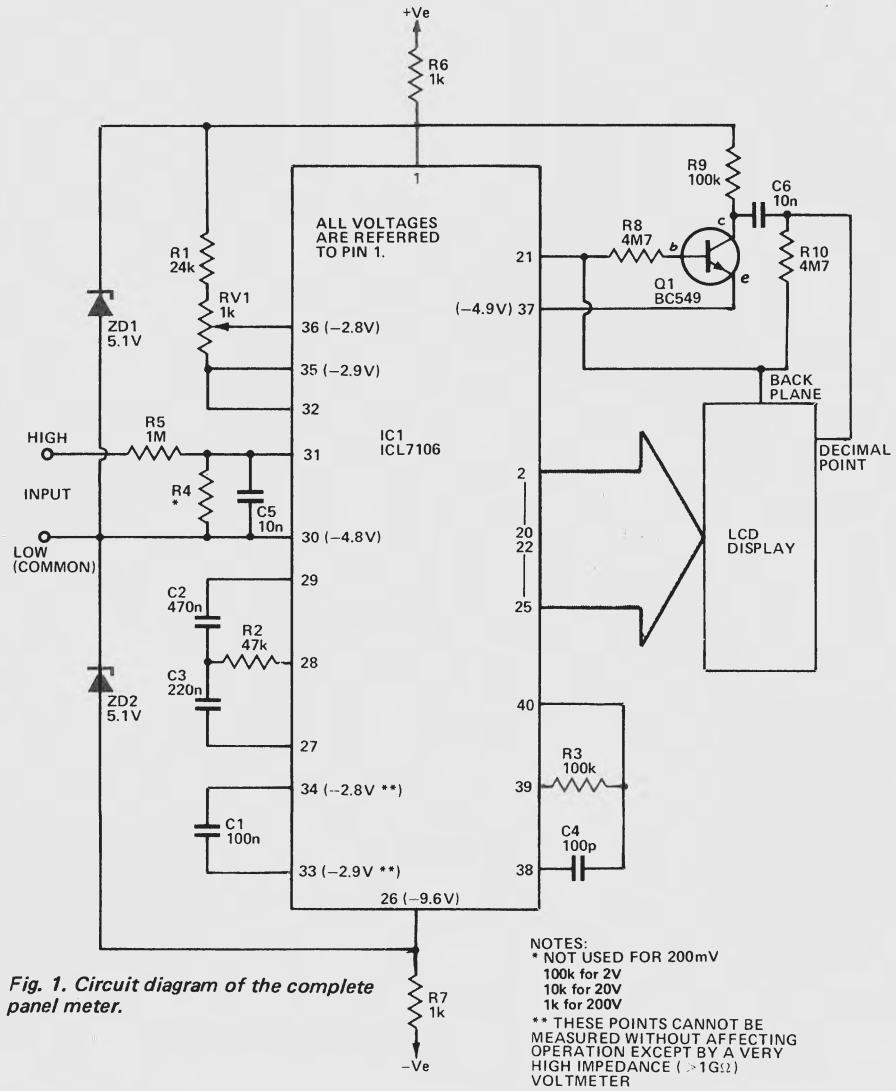


Fig. 1. Circuit diagram of the complete panel meter.

HOW IT WORKS – ETI 135

Not much can be said on how this project works as everything is done by one IC and if anything goes wrong it is usually the IC. We have included some waveform diagrams and voltages for reference purposes. The conversion works on the dual-slope integration technique, which is the most reliable of the simple methods available. A capacitor is charged up at a rate proportional to the input voltage for a predetermined time (in this case 1000 clock pulses), then it is discharged at a constant rate until it reaches the starting point again. The time taken to do this (i.e. the number of clock pulses) is proportional to the input voltage.

It is a true dual polarity system where the integration direction depends on the polarity of the input voltage. Provided AC ripple on the input averages to zero over 1000 clock pulses it will be rejected, hence where 50Hz mains is to be rejected a 50 kHz clock should be used, giving 80 ms sample time (4 cycles of 50 Hz). The clock can be adjusted by varying R3 if desired.

The printed circuit board layout for this project is on page 56.

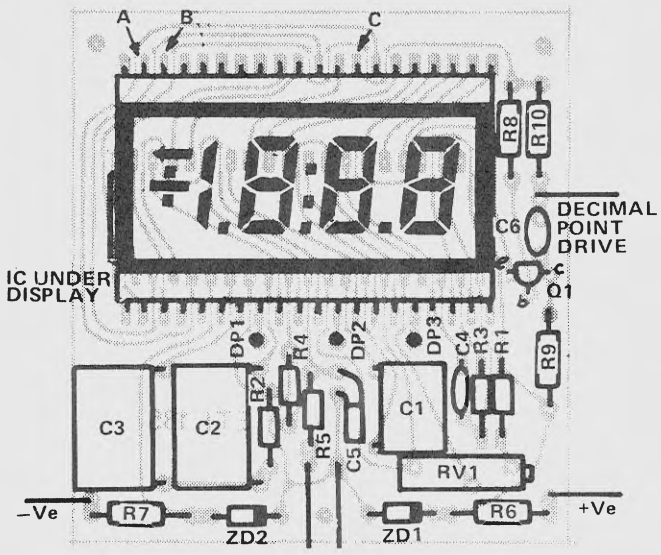


Fig. 2. Component overlay with the display in place. Points marked A, B and C are the unused display segments – the vertical part of the + sign, the arrow and the semicolon respectively.

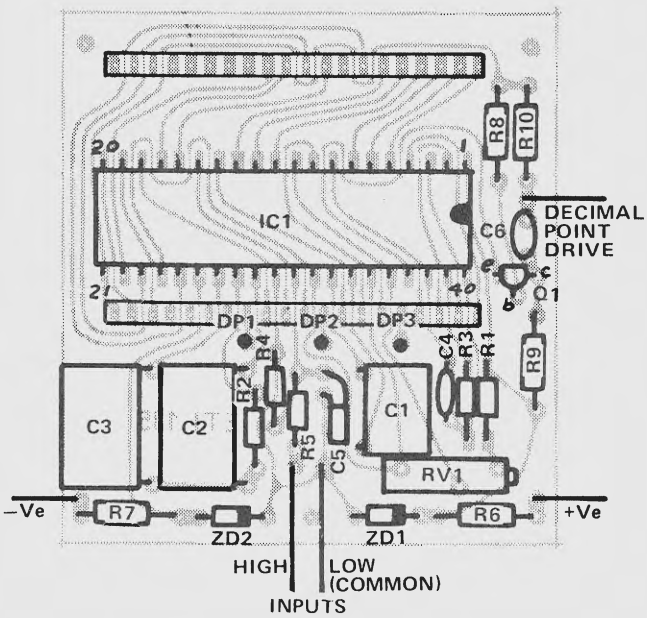


Fig. 3. The component overlay without the display showing the positioning of the integrated circuit.

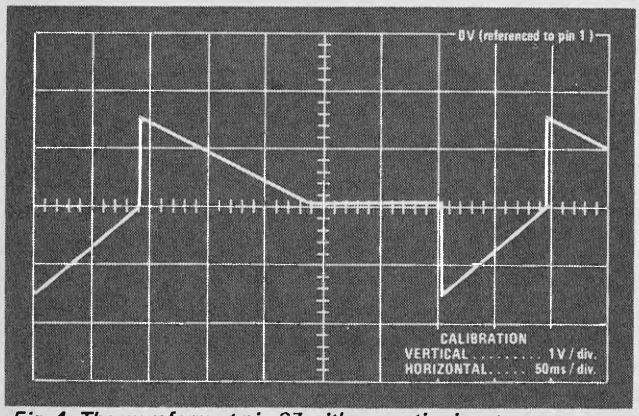


Fig. 4. The waveform at pin 27 with a negative input voltage of about 170mV.

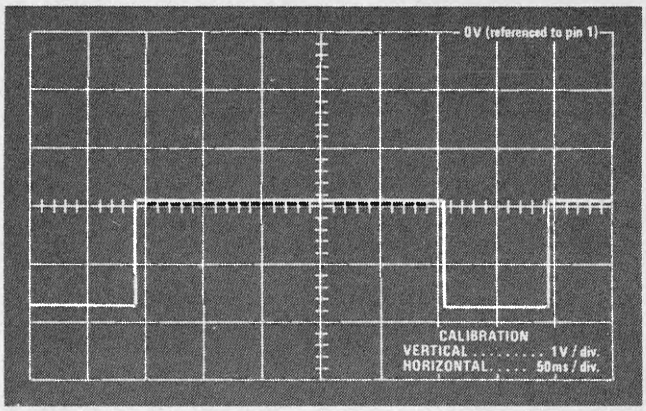


Fig. 7. The waveform at pin 28.

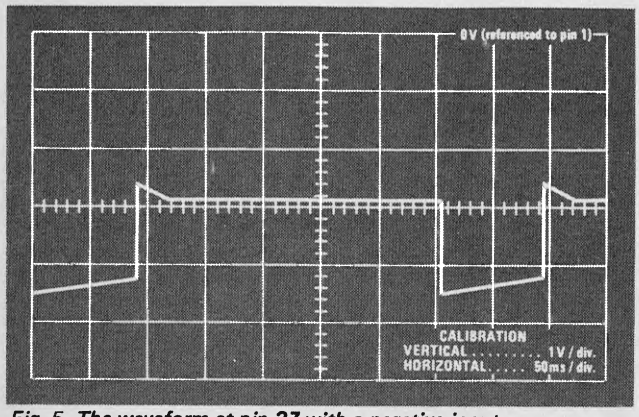


Fig. 5. The waveform at pin 27 with a negative input voltage of about 30mV. Compare this with Fig. 4.

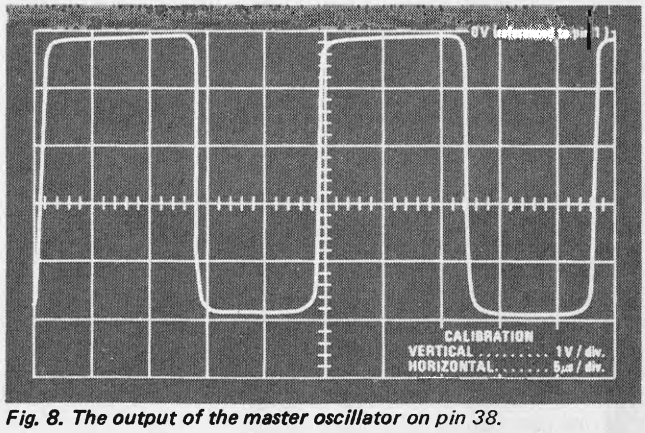


Fig. 8. The output of the master oscillator on pin 38.

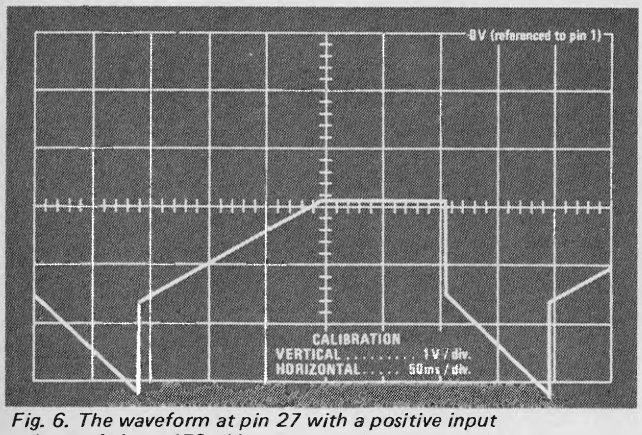


Fig. 6. The waveform at pin 27 with a positive input voltage of about 170mV.

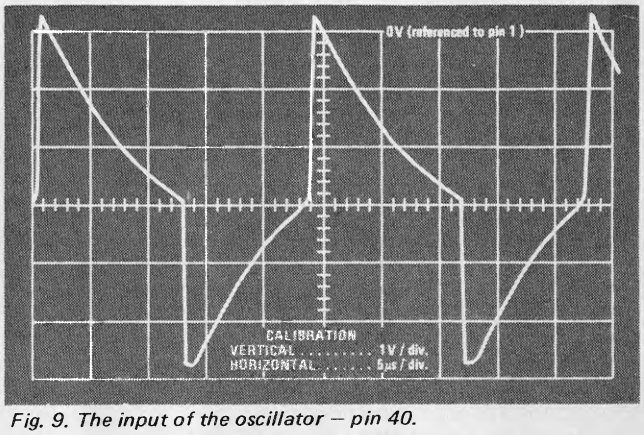


Fig. 9. The input of the oscillator – pin 40.

PARTS LIST – ETI 135

Resistors all ¼ or ½ W, 5%
- R1* 24k
- R2* 47k
- R3* 100k
- R4 . . . . . see circuit diagram
- R5* 1M
- R6 . . . . . 1k
- R7 . . . . . 1k
- R8 . . . . . 4M7
- R9 . . . . . 100k
- R10. . . . . 4M7

Potentiometers
- RV1* . . . . . 1k 10 turn trim

Capacitors
- *C1 . . . . .100n polyester
- *C2 . . . . .470n "
- *C3 . . . . .220n "
- *C4 . . . . .100p ceramic
- C5,6 . . . .10n polyester

Semiconductors
- IC1* ICL7106
- Q1 . . . . . BC549
- ZD1,2 . . . . 5.1V 300mW

Miscellaneous
- PC board ETI 135
- LCD display
- * Socket for LCD display

* These components are supplied with the Intersil ICL7106EV evaluation kit.

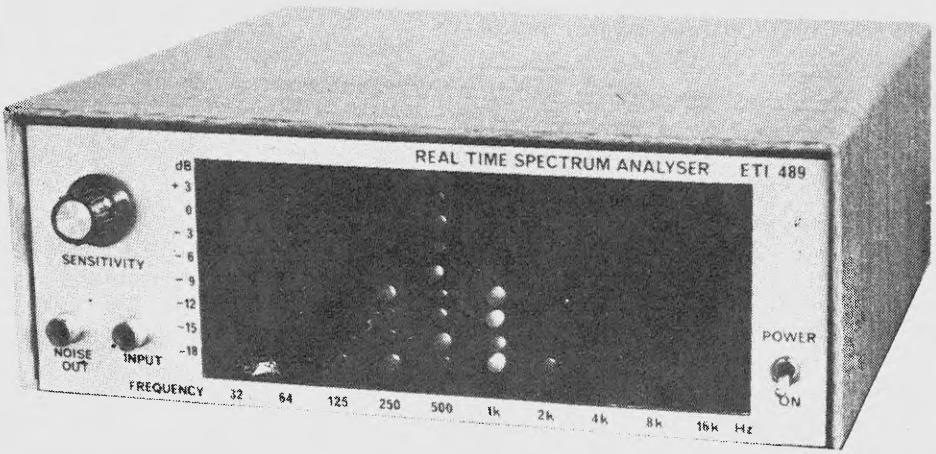
The Intersil evaluation kit which contains most of the components for this project is available from R & D Electronics, 23 Burwood Road, Burwood, Victoria 3125. Sydney address is 133 Alexander Street, Crows Nest, NSW. 2065.

Audio spectrum analyser 2

LED display for compact, easy-to-build unit.

OUR PREVIOUS Real Time Audio Analyser design produced beautiful displays on the screen of an oscilloscope but this means, of course, that to use the device one has to have a scope. Not everyone has, and with this in mind, we contemplated the design of a more conventional analyser with LED bar-graph display. Urged on by reader response to our hint that this design was on the cards, we have gone ahead and produced the project in double-quick time.

This version has the great advantage of portability over the previous design, and also looks better than a scope sitting next to your brand new, 21st century styled hi-fi! It is also easier to set up and trouble-shoot.



Design Features

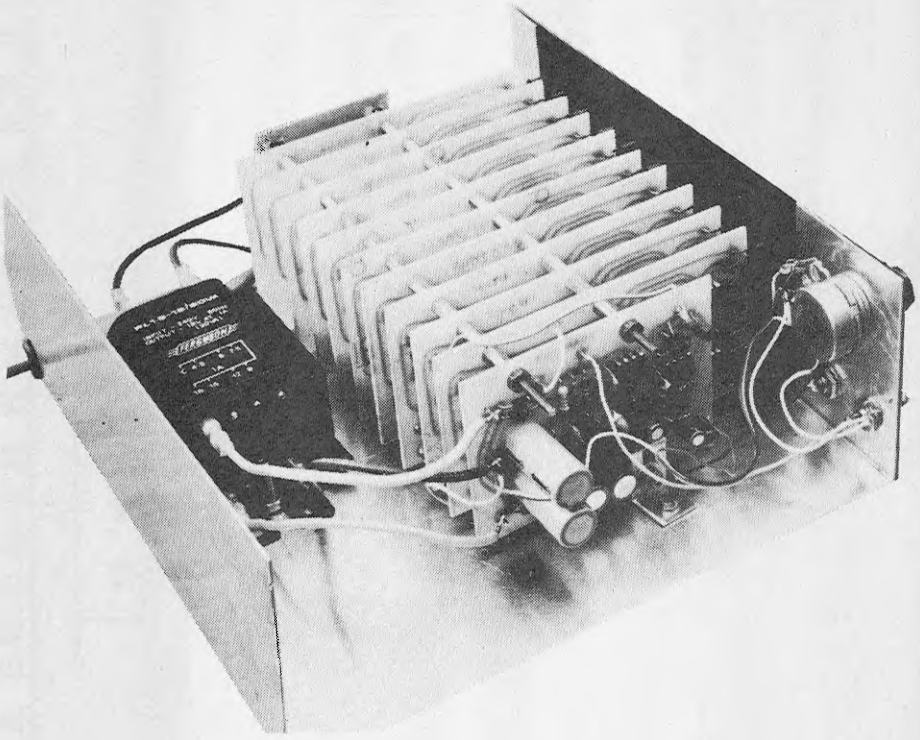
When we proposed a LED version of the spectrum analyser we initially were going to use the original filter board and design a new logic board which multiplexed the LED display. The only question at that time was whether to multiplex the LEDs as columns or as individual LEDs. The column method is easier on the power supply as the peak current is only 10 times the average current while singly the peak current is 80 times the average. This is not quite accurate because a multiplexed LED requires less average current for the same output than one continuously on. However the column method also requires one extra diode per LED to give the isolation required between columns.

SPECIFICATION – ETI 489

No. of bands	10
Frequencies	31, 63, 125, 250, 500, 1k, 2k, 4k, 8k, 16k
Filter characteristics	–12dB, one octave from nominal centre frequency
Display	LED display 3dB spacing
Input level	50mV – 10V
Input impedance	47k
Pink noise output	200mV

After struggling with the PC board layout which was developing into a double sided board similar to the filter board of the previous analyser, we decided there must be an easier way to make a living! The question was then raised of whether it was worthwhile to multiplex the display at all and the answer was the project as it appears here.

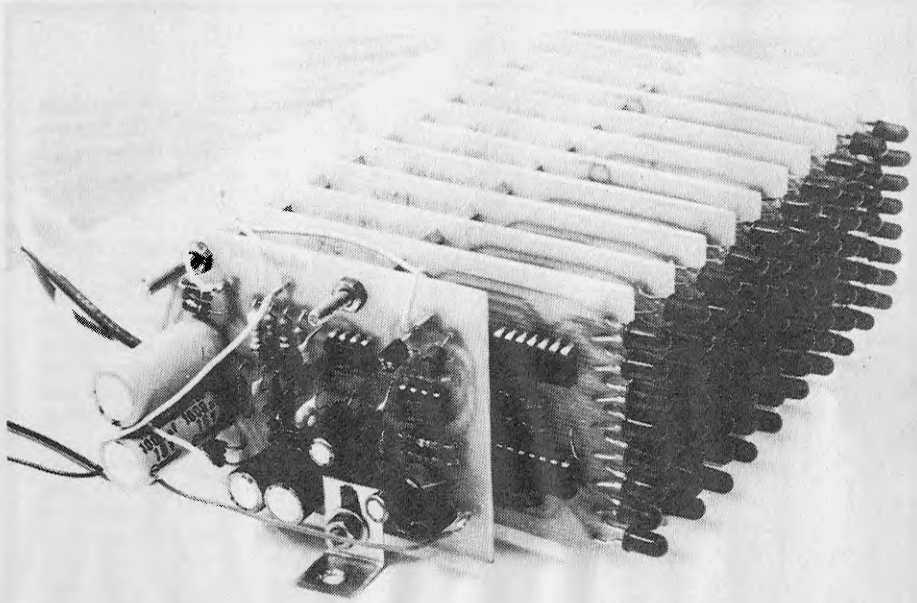
The individual board approach not only makes fault finding easier and less likely, it also allows single sided PC boards to be used throughout. The system can also be expanded (or cut down) as desired simply by changing the filter components and the number of display boards. The power supply is capable of supplying up to 20 display boards without increasing the filter capacitors.



Construction

Assemble the power supply board and the ten filter display boards with the aid of the overlays. The filter components can be selected from Table 1 noting that when the tantalum capacitors are used in the three lower octaves a bias resistor R15 is needed. The LEDs should be installed as evenly as possible with the polarity correct.

We assembled the units on 1/8" brooker rod with 12.5mm spacers between the boards. Metal brackets are used at each end to support the assembly. On the filter display boards the power rails and the input are all common and for the power supply we used long lengths of tinned copper wire threaded through the holes. The input lead should be done with separate links to allow the units to be serviced later if needed.



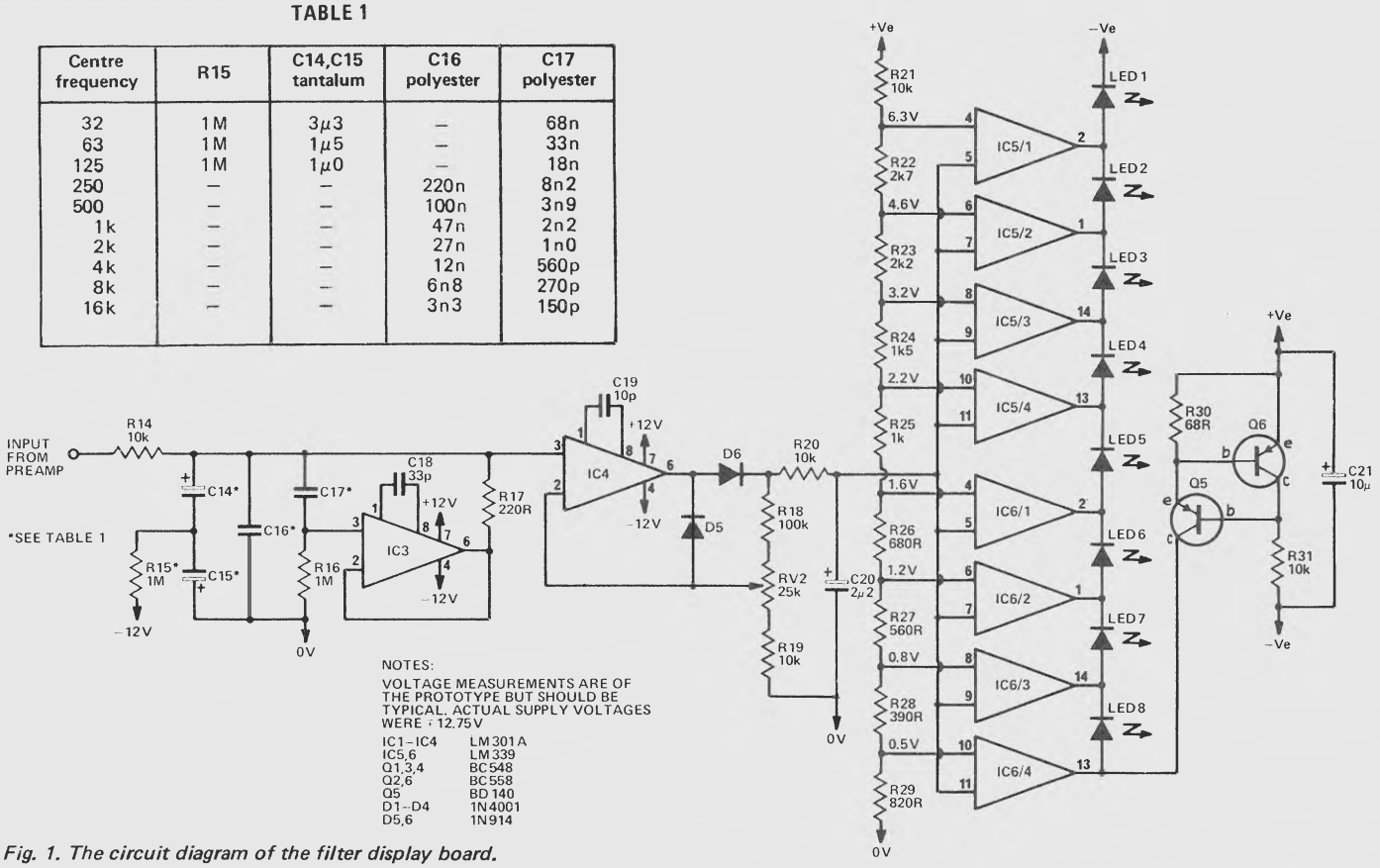
Before assembling the unit however each board should be checked with an oscillator to check it for the correct frequency and to adjust the calibration potentiometer. This is best done by measuring the sensitivity of the 16 kHz board with RV2 set for maximum sensitivity and adjusting all the others till they are the same.

We made a metal box with a piece of red perspex for a window to house the unit. If it is to be used with an equaliser (such as the ETI 484) it could be built into the same box.

It will be found with the economical LEDs available that there will be a difference in brilliance between them. If desired matched LEDs are available but not for 20 cents each!

TABLE 1

Centre frequency	R15	C14,C15 tantalum	C16 polyester	C17 polyester
32	1M	3μ3	–	68n
63	1M	1μ5	–	33n
125	1M	1μ0	–	18n
250	–	–	220n	8n2
500	–	–	100n	3n9
1k	–	–	47n	2n2
2k	–	–	27n	1n0
4k	–	–	12n	560p
8k	–	–	6n8	270p
16k	–	–	3n3	150p



NOTES:
VOLTAGE MEASUREMENTS ARE OF THE PROTOTYPE BUT SHOULD BE TYPICAL. ACTUAL SUPPLY VOLTAGES WERE ±12.75V

IC1–IC4	LM301A
IC5,6	LM339
Q1,3,4	BC548
Q2,6	BC558
Q5	BD140
D1–D4	1N4001
D5,6	1N914

Fig. 1. The circuit diagram of the filter display board.

HOW IT WORKS – ETI 489

The input signal to the unit is initially buffered and amplified by IC1 and is then split into octave bands, rectified and displayed by a "bar" of LEDs. We have used 10 separate boards for the rectifier-display as only the component valves in the filter are different.

The filter is a parallel LC network where the inductive part is a gyrator formed by IC3, C17, R16 and R17. The value of such an "inductor" is R16 x R17 x C17 Henrys (C17 in Farads). This, with the parallel capacitor C16 and the series resistor R14, form a band pass filter.

The output of the filter is half wave rectified by IC4 which also provides a gain of about 5 before the signal is smoothed by C20.

The eight LEDs in each individual display are connected in a series chain which is supplied with 10 mA by the constant current source Q5, Q6. Control of how many LEDs will be on is done by IC5 and IC6. These are quad voltage comparators which have as the output stage an open collector NPN transistor with its emitter connected to the negative supply rail. These compare the output of the rectifier with the voltage set on the resistive divider R21-R29 and "short" out the unwanted LEDs.

The power supply is a simple fullwave rectified with a centre tap giving ∓12V dc. Due to the load (about 150 mA) there is about one volt ripple on the supply rail but this does not affect the operation of the unit. As the current drawn by the filter display boards does not change with the number of LEDs on the supply voltage remains reasonably constant.

The 100 Hz ripple does however affect the noise generator and this has been changed from the 487 analyser to accommodate this. The noise generator consists of Q3 which is used as a zener diode where the noise current is amplified by Q4. The output of Q4 is white noise and to give pink noise a 3 dB/octave filter is needed. IC2 and the associated capacitors and resistors provide this filter.

PARTS LIST – ETI 489A

Filter–Display boards 10 required

Resistors all ¼W 5%

R14. . . . . 10k
R15. . . . . see table 1
R16. . . . . 1M
R17. . . . . 220R
R18. . . . . 100k
R19–R21 . . 10k
R22. . . . . 2k7
R23. . . . . 2k2
R24. . . . . 1k5
R25. . . . . 1k
R26. . . . . 680R
R27. . . . . 560R
R28. . . . . 390R
R29. . . . . 820R
R30. . . . . 68R
R31. . . . . 10k

Potentiometers

RV2 . . . . . 25k trim

Capacitors

C14–C17 . . see table 1
C18. . . . . 33p ceramic
C19. . . . . 10p ceramic
C20. . . . . 2μ2 25V electro*
C21. . . . . 10μ 25V electro*

Semiconductors

IC3,4 . . . . . LM301A
IC5,6 . . . . . LM339
Q5 . . . . . BD140
Q6 . . . . . BC558
D5,6 . . . . . 1N914
LED1–LED8

Miscellaneous

PC board ETI 489A

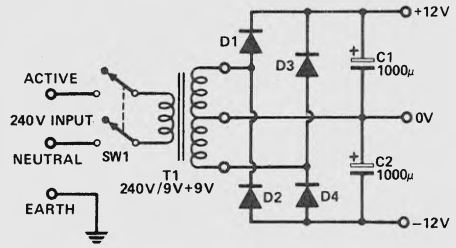


Fig. 2. The power supply circuit.

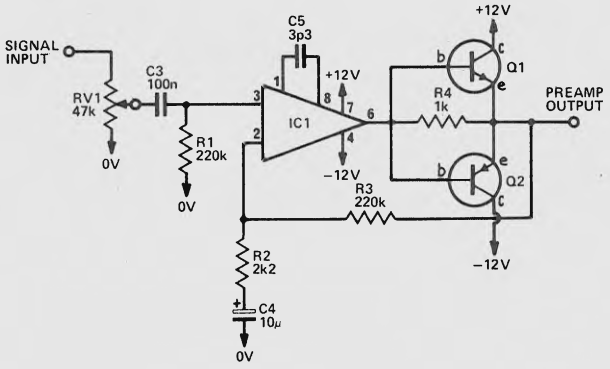


Fig. 3. The circuit of the preamplifier–buffer.

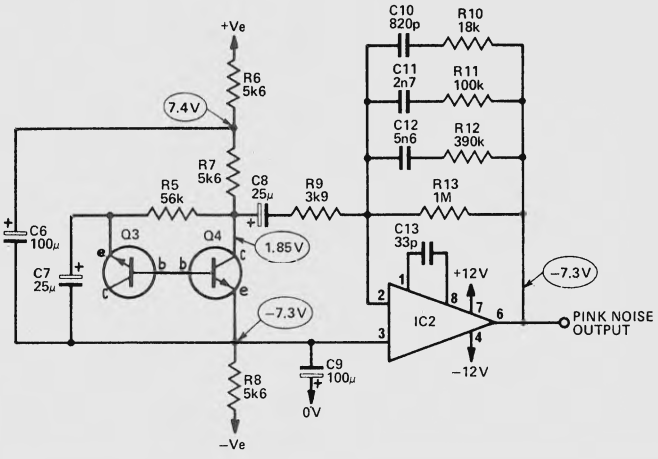
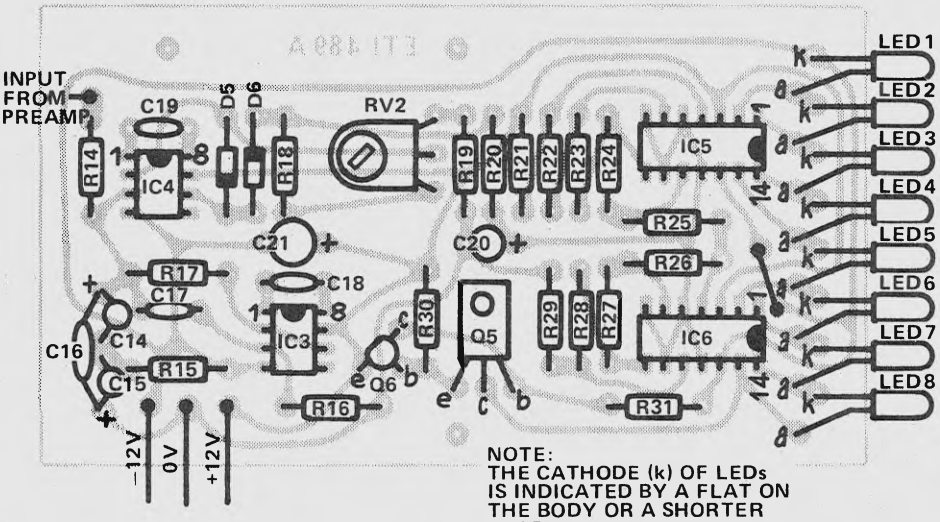


Fig. 4. The circuit diagram of the pink noise generator.



NOTE:
THE CATHODE (k) OF LEDs IS INDICATED BY A FLAT ON THE BODY OR A SHORTER LEAD.

Fig. 6. The component overlay of board A.

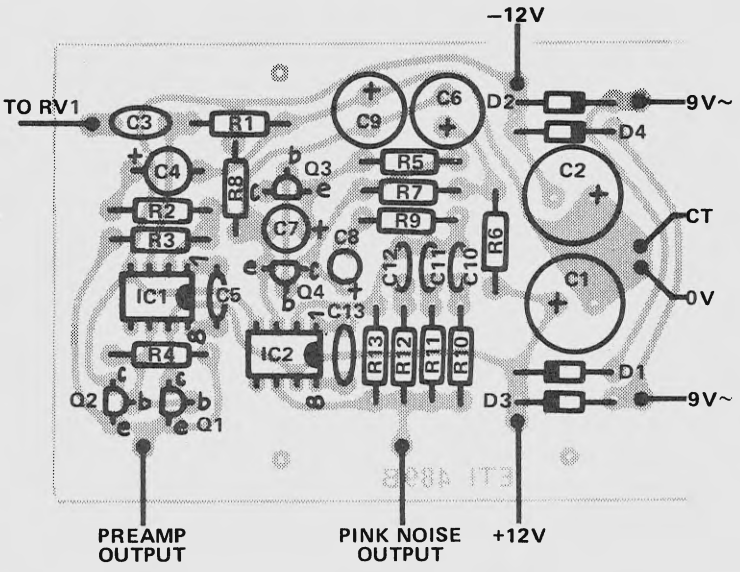


Fig. 5. The component overlay of board B.

The printed circuit boards for this project are on page 16.

PARTS LIST – ETI 489B

Power Supply board

Resistors all ½W 5%
R1 . . . . . 220k
R2 . . . . . 2k2
R3 . . . . . 220k
R4 . . . . . 1k
R5 . . . . . 56k
R6–R8. . . . 5k6
R9 . . . . . 3k9
R10. . . . . 18k
R11. . . . . 100k
R12. . . . . 390k
R13. . . . . 1M

Potentiometers
RV1 . . . . . 47k log rotary

Capacitors
C1,2 . . . . . 1000μ 16V electro*
C3. . . . . 100n polyester
C4. . . . . 10μ 25V electro*
C5. . . . . 3p3 ceramic
C6. . . . . 100μ 25V electro*
C7,8 . . . . . 25μ 25V electro*
C9. . . . . 100μ 25V electro*
C10 . . . . . 820p ceramic
C11 . . . . . 2n7 polyester
C12 . . . . . 5n6 polyester
C13 . . . . . 33p ceramic

Semiconductors
IC1,2 . . . . . LM301A
Q1 . . . . . BC548
Q2 . . . . . BC558
Q3,4 . . . . . BC548
D1–D4. . . . 1N4001

Miscellaneous
PC board ETI 489B
Transformer 240V/9V+9V PL18/20VA
SW1 DPDT 240V toggle switch
Case to suit

*all electrolytic capacitors PC board or single ended type.

Audio power meter

This design multiplies voltage and current to come up with the correct value of power, using an analogue multiplier IC.

POWER IS PROBABLY the least understood and most misrepresented quantity in the electrical measurement system. This is especially so in the area of audio amplifier and speaker specifications when terms like peak, peak to peak, music and RMS are related to power.

Power is simply the rate at which energy is being used. It is expressed in watts and the value may vary from femtowatts (10^{-12} W), as in the input power of a FET, to thousands of megawatts in the power generation field. The term thousand megawatts is generally used in preference to the more correct term, gigawatts.

Power can be calculated simply by multiplying voltage and current:

$$P = EI$$

In a dc circuit where both voltage and current remain constant no problem arises. However in an ac or a dc circuit where the voltage is not constant with time, this formula only holds for instantaneous power as the power varies with time. Power as we usually use the term is the time average of this. If the load is resistive, i.e. contains no inductance or capacitance, and we can measure the RMS value of the voltage, we can still use this simple formula. However measuring the RMS voltage is not easy as most voltmeters measure the peak or average rectified voltage with a suitable scaling factor built in to give a correct result when measuring a sine wave signal.

If the load is reactive the current and voltage will no longer be in phase, i.e. the peaks do not occur at the same point in time. The difference can be expressed either by the phase angle in degrees or by the cosine of this angle (known as the power factor). The current waveform can either be ahead of the voltage (leading) or behind it (lagging). Capacitive circuits give rise to a leading power factor while inductive circuits lag.

If working with a sine wave, and if the power factor is known, the formula for power can be expressed as:

$$P = EI \cos \phi$$

where ϕ is the phase angle. In a dc circuit $\cos \phi$ is unity so the formula holds for this case as well. An example is a 40 W fluorescent light which takes 430 mA from the 240 V mains. At first sight, this implies a power consumption of over 100 W, until it is realised that its power factor is about 0.45 lagging. The formula above, using $\cos \phi = 0.45$, thus gives a power consumption of only 46.4 W. (The additional 6 odd watts is dissipated in the ballast). The product of voltage and current is known as the VA rating and is used when calculating the currents in a circuit. If a capacitor is connected across a sine wave ac circuit the current taken can be calculated by dividing the voltage by the reactance of the capacitor. While this circuit draws current, it has a power factor of very near zero (90° phase lead) and therefore takes no power! By adding the correct amount of capacitance to an inductive circuit (i.e. the fluorescent light) the power factor can be altered, reducing the current drawn (but not the power).

Confused yet?

Getting back to audio amplifiers and their ratings, the problem lies in the complex nature of the music waveform and how to specify the amplifier's rating. As the waveform is far from a constant sine wave with the peak power being anything up to 20 times the average, numerous methods such as peak power, peak to peak power, music power, etc. evolved. However, for a long time there was no set standard, and one amplifier advertised with a 50 W (music) rating was in fact a 5 W stereo amplifier. The situation got so out of hand that the US Government brought down legislation on how amplifiers were to be tested. This is with a continuous sine wave signal with level set so that the distortion is at a specified level and power calculated from the RMS output voltage: hence the term RMS power. Note however that the term RMS refers to the method of measurement, i.e. the use of RMS voltage, and it is not the RMS value of the power waveform. It is, in fact, the average of the power waveform.

Speakers are just as confusing. They are normally specified not in terms of the power they can dissipate, but the maximum power of amplifier they are suitable for. This is due to the fact that music is never (well, rarely) a

SPECIFICATION – ETI 138

Power range	30mW – 3000W FSD in eleven ranges
Input impedance	
1V	47k
3V–300V	100k
10A	0.1 ohm
3A	0.32 ohm
1A	1 ohm
0.3A	3.2 ohm
0.1A	10 ohms
0.03A	32 ohms
Overload capability	
Voltage ranges	RMS – 200% peak – 300%
Current ranges	RMS – 100% peak – 300%
Accuracy	< 5%
Frequency range	dc to 100kHz

continuous sine wave and the average power in the speaker may be only 10% of the RMS rating of the amplifier, even with the amplifier clipping.

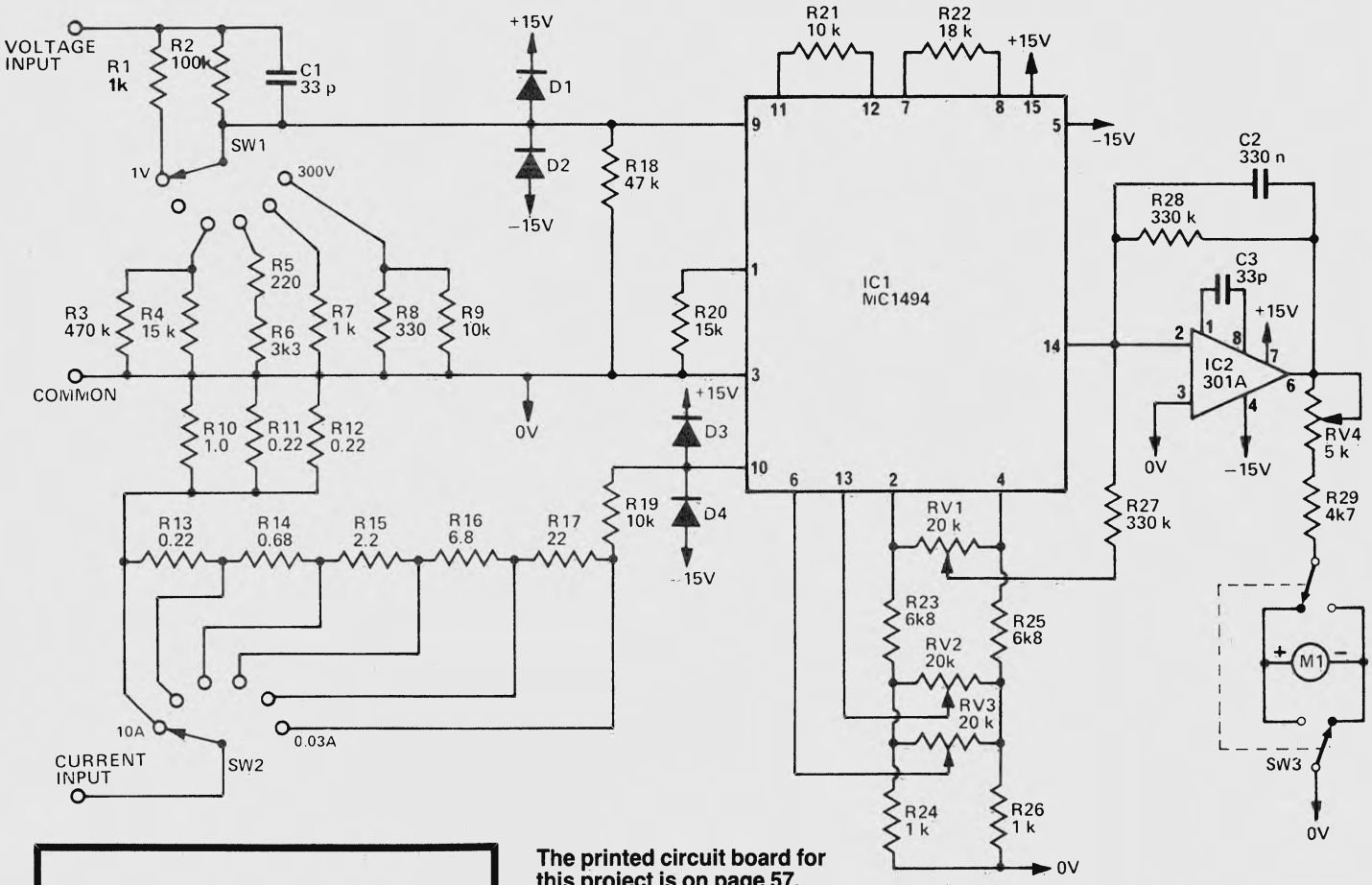
To measure the power actually being delivered to the speaker under music conditions, a wattmeter must be used.

Design Features

To multiply current and voltage together we had the choice of analogue or digital techniques. Unfortunately while digital is the 'in' thing, offering versatility and accuracy, it is not fast enough to calculate the instantaneous power on high frequencies. We therefore chose the analogue method.

Looking around for ICs, the only ones with reasonable price and availability were the MC1494, 1495 and 1496. The 1496 (or 796) is the cheapest and most readily available, but has the disadvantage of not being able to multiply dc signals or ac signals with a dc offset. The 1494 and 1495 are about the same price (around $7.00), and of the two, the 1494 was more linear and easier to use.

We chose not to use any input buffer on the voltage input but had to pay the penalty of having a lower input impedance than normal with voltmeters.



The printed circuit board for this project is on page 57.

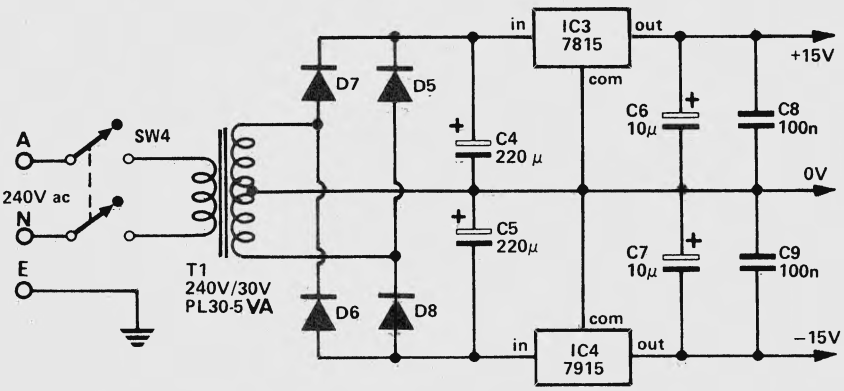
HOW IT WORKS – ETI 138

Power is the product of current and voltage. This holds irrespective of the nature of the load, provided you are talking about instantaneous power. By multiplying current and voltage together and then taking the average of these instantaneous values we find the true power. Again this works irrespective of the load.

In this circuit the multiplying is done by IC1 (MC1494), the output of which is a current proportional to the product of the inputs. For more detailed notes on this IC, see the separate section. The current output of this IC is converted to a voltage by IC2 with C2 providing the averaging. The meter is then simply wired across the output of this IC with a meter reversing switch provided. This reversing switch is needed not to measure negative power, but to correct for reversed readings due to differing external connections.

The power supply is a full wave bridge with a centre tap giving about ∓20 V dc which is then regulated to the ∓15 V required by IC1.

Adjustments for zeroing the voltage and current inputs are provided by RV2 and RV3 while RV1 compensates for offsets in the output. These are supplied by a stable ∓4 V reference in IC1. Range switching is done by SW1 and SW2. Protection against overvoltaging the IC is provided by D1 – D4.



F1g. 1 The circuit diagram of the audio power meter.

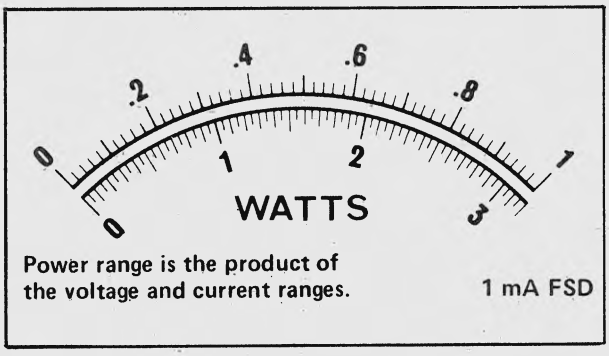


Fig. 2 The meter scale used. It is designed for the TD86 meter.

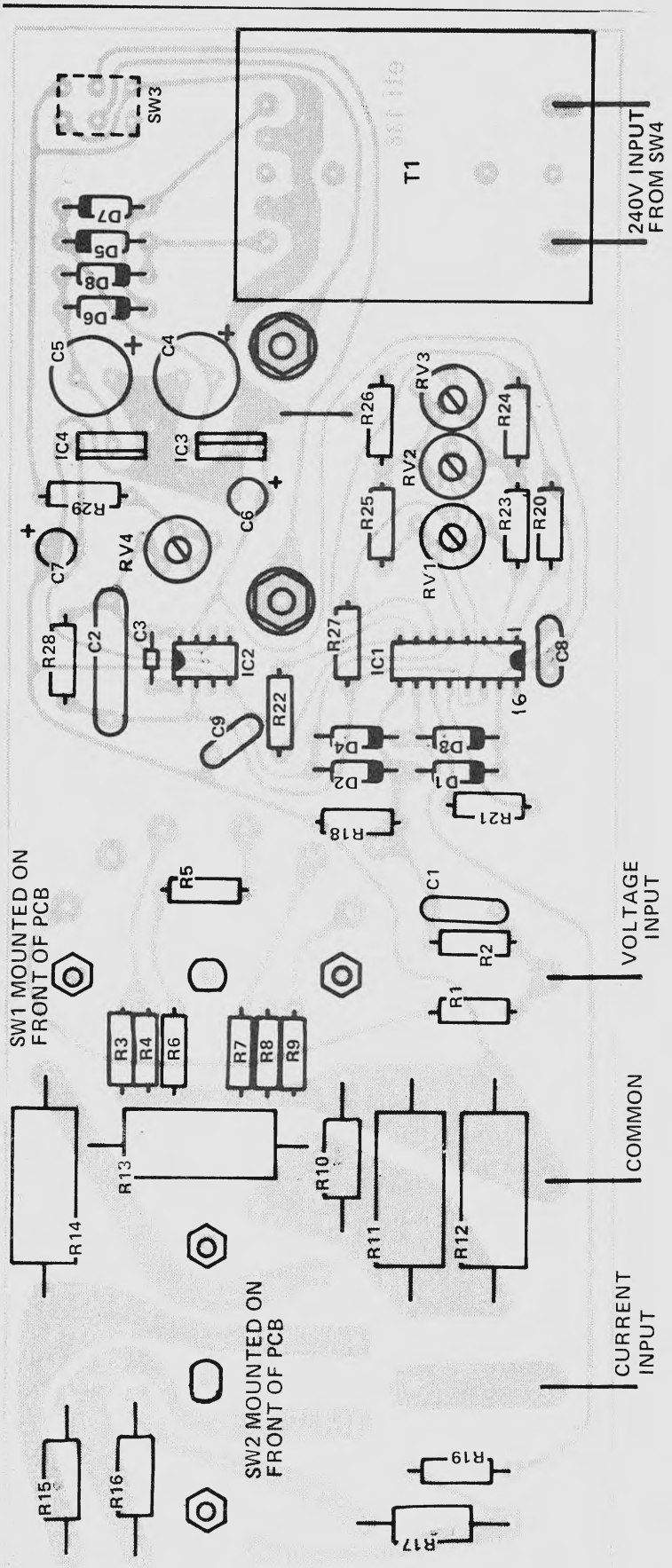


Fig. 3. The component overlay of the power meter.

PARTS LIST – ETI 138

Resistors all ½% 5W unless stated

R1 . . . . . 1k
R2 . . . . . 100k
R3 . . . . . 470k
R4 . . . . . 15k
R5 . . . . . 220R
R6 . . . . . 3k3
R7 . . . . . 1k
R8 . . . . . 330R
R9 . . . . . 10k
R10. . . . . 1 ohm 1W
R11–R13 . . 0.22 ohm 5W
R14. . . . . 0.68 ohm 5W
R15. . . . . 2.2 ohms 1W
R16. . . . . 6.8 ohms 1W
R17. . . . . 22R
R18. . . . . 47k
R19. . . . . 10k
R20. . . . . 15k
R21. . . . . 10k
R22. . . . . 18k
R23. . . . . 6k8
R24. . . . . 1k
R25. . . . . 6k8
R26. . . . . 1k
R27, 28 . . . 330k
R29. . . . . 4k7

Potentiometers

RV1–RV3. . 20k trim
RV4 . . . . . 5k trim

Capacitors

C1. . . . . 33p 500V ceramic
C2. . . . . 330n polyester
C3. . . . . 33p ceramic
C4, 5 . . . . . 220μ 35V electro
C6, 7 . . . . . 10μ 25V electro
C8, 9 . . . . . 100n polyester

Semiconductors

IC1 . . . . . MC1494
IC2 . . . . . 301A
IC3 7815
IC4 7915

D1–D4. . . . 1N914
D5–D8. . . . 1N4004

Miscellaneous

PC board ETI 138
SW1, 2 two pole 6 position 10A rotary switches (Paton Electrical)
SW3, 4 two pole toggle switches
Transformer PL30/5VA
Meter 1mA FSD (TD86)
Three binding posts
Instrument case 255x100x205mm
Power cord and clamp
Two knobs
Front panel

Using the Power Meter

To use the meter we must measure both voltage and current. There must be a common point for these measurements. The current connection can be in either of two ways as shown in the drawings below. One measures the power out of the supply and the second the power into the load. The difference? The current shunt in the wattmeter drops one volt when working at the full range value and this may or may not affect the reading. At 10 A this accounts for 10 W which, if the power being measured is only 100 W, is a 10% error – although if the measured power is 2400 W the error is only 0.4%.

The range of the meter is the product of the individual ranges, i.e. on 30 V and 1 A the fsd is 30 W, while 30 V and 3 A gives 100 W fsd. To help give a reading reasonably high on the scale, the voltage range can be overvoltaged by a factor of 2. Due to power dissipation problems this should not be attempted on the current ranges. The peak voltage or current can be as high as three times the range value.

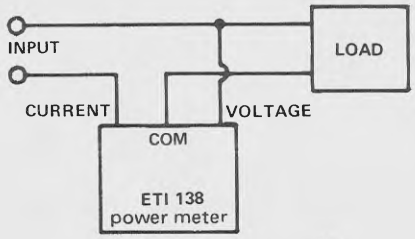


Fig. 4 This connection measures the power into the load.

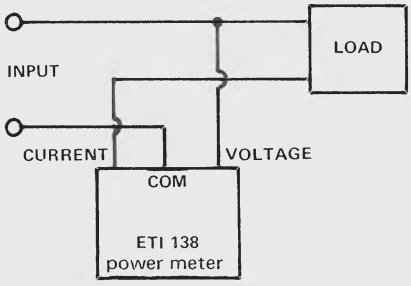


Fig. 5 This connection measures the power out of the supply.

Construction

We mounted all the components associated with the meter and the switches on a single pc board and if the same or similar case is to be used this is recommended.

Except for the meter and the switches the components are mounted on the 'normal' side of the pc board. These should be mounted first with the only critical part of the assembly in the area of the range switches. Here the high powered resistors should be spaced at least 5 mm from the pc board as they run hot at maximum current. Also the leads of all the resistors in this area should be cut off close to the pc board after soldering. This is to give adequate clearance to the rotary switches. We used two self tapping screws into the plastic of the transformer case to help fix it onto the board. We have made allowance for either the cermet (VTP) or the normal carbon trim potentiometer.

The switches used are made by Paton Electrical Pty. Ltd of 90 Victoria St., Ashfield, NSW, and were chosen as they are rated for 10 A 240 V operation. If desired the voltage switch may be the normal type rotary switch which will reduce the cost a little. As supplied, these switches have a bakelite brace at the rear to give support. We undid the nuts and removed this piece (carefully as the switch may spring apart) and then fitted it to the copper side of the board, retained by the nuts. The pc board then acts as the the rear support for the switch. A glance at the photographs of the unit should make this clear. Rotate the switch and check that the contacts do not touch any of the solder joints on the PC board. The contacts can now be wired to the pc board using heavy tinned copper wire for the current switch as there is up to 10 Amps flowing.

Mount the meter onto the front panel along with the two toggle switches and the binding posts. Remove the nuts from the voltage switch, leaving one on the current switch and then mount the pc board onto the meter. Run the nut on the current switch up to the back of the front panel and then fit the second nut on the the front side.

The toggle switches can now be wired along with the power wiring, fitting the knobs ready for calibration.

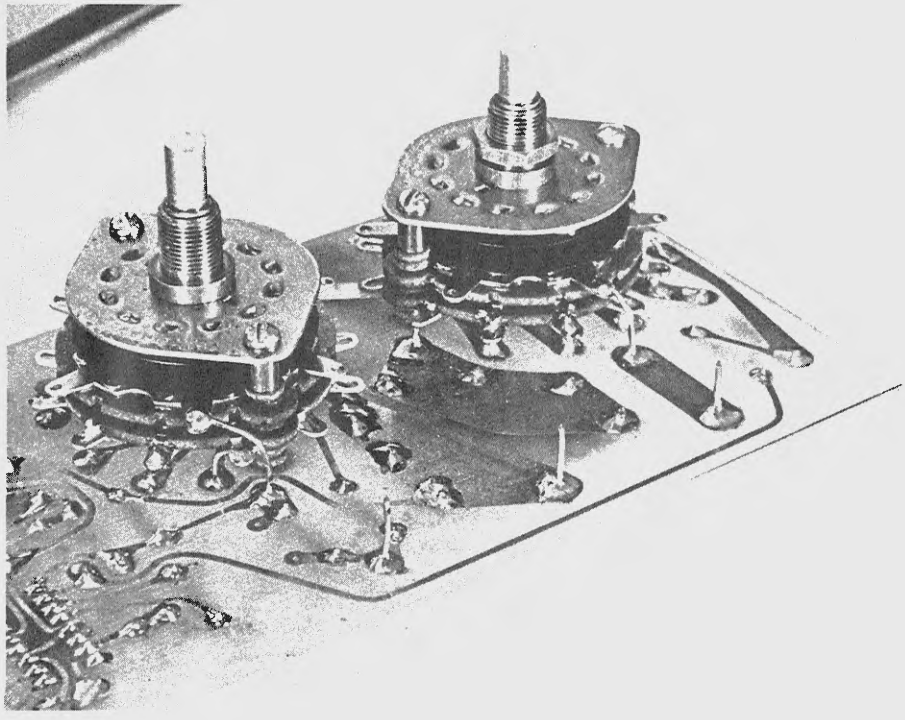
Calibration

Four adjustments are required, which are performed as follows:

Select the 1 V and 0.03 A ranges and switch on. If the meter reads in reverse, toggle SW3. Don't worry about the reading unless it is off scale. If it is, adjust RV1 to bring it back towards zero. Now apply a voltage of about 1 V dc to the voltage input and note the meter deflection. Adjust RV2* until there is no deflection when this voltage is applied. Now apply the voltage to the current input (it will take about 30 mA) and adjust RV3 until there is no deflection. Recheck the voltage input and readjust if necessary.

Now with no voltage applied adjust RV1 to give zero output. Apply exactly 1 V to both current and voltage inputs and adjust RV4 to make the meter read FSD.

This is all the calibration that should be necessary.



About the 1494

The 1494 is a variable transconductance multiplier with a bidirectional current source output. What this means is that it looks at the voltage on the two inputs and gives an output current proportional to the product of the two. Typical applications include: multiply, divide, square, square root, phase detection, frequency doubling, balanced modulation/demodulation and electronic gain control. An internal circuit diagram is given below for those interested.

Values and Limitations

1 For best temperature coefficient R1 (pin 1 to 0V) should be 16k(we used 15k as it is easier to obtain). This sets the value of all the current sources inside the IC ($I_1 = 8/R1$)
2 The value of Rx (pin 11 to pin 12) should be≥3x peak input voltage(X) expressed in k ohms.
3 The value of Ry (pin 7 to pin 8) should be ≥6x peak input voltage(Y) expressed in k ohms
4 Choose the scaling factor required ie Vout = K.Vx.Vy
5 Load resistance (pin 14 to 0V) can be calculated by RL=(K.Rx.Ry.I1)/2
6 If RL is connected between pin 14 and 0V without an inverting amp. the frequency response is limited by the output capacitance of 10pF.
7 For best temperature coefficient the load between pins 2 and 4 should be 8.6k.

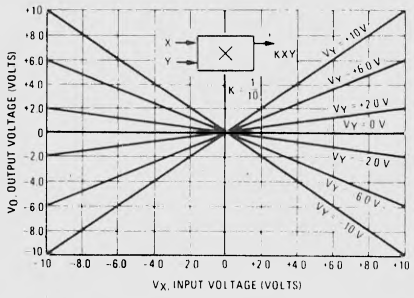


Fig. 6. Transfer characteristics of the IC.

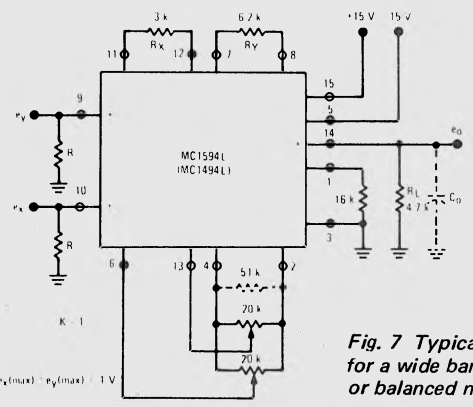


Fig. 7 Typical connections for a wide band multiplier or balanced modulator.

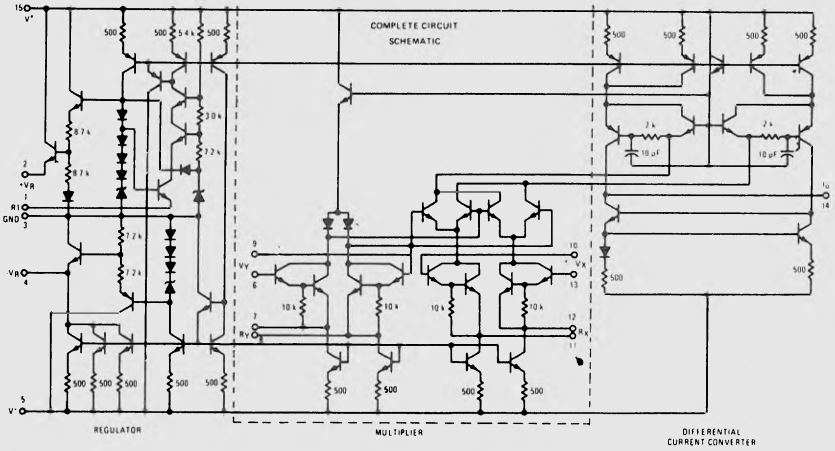


Fig. 8 The internal circuit diagram of the IC.

Fig. 9 Typical connection of a low frequency multiplier. For a squaring circuit simply parallel the two inputs. In this case pin 6 can be connected to 0V and P1 deleted.

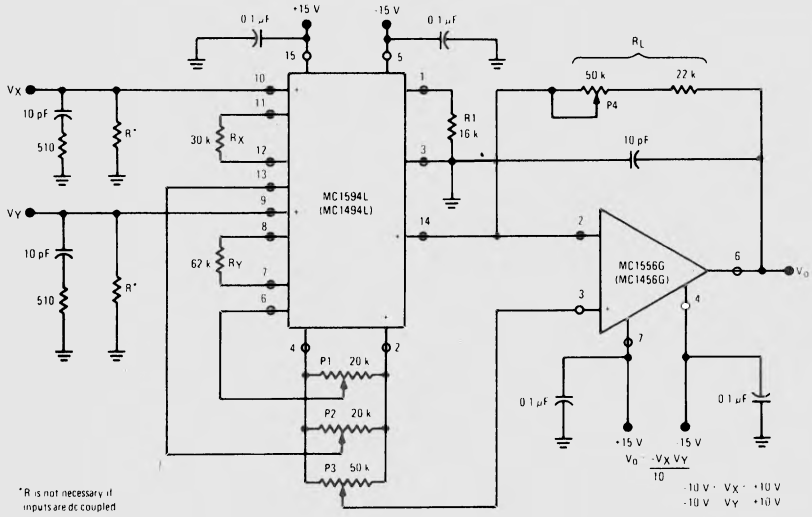
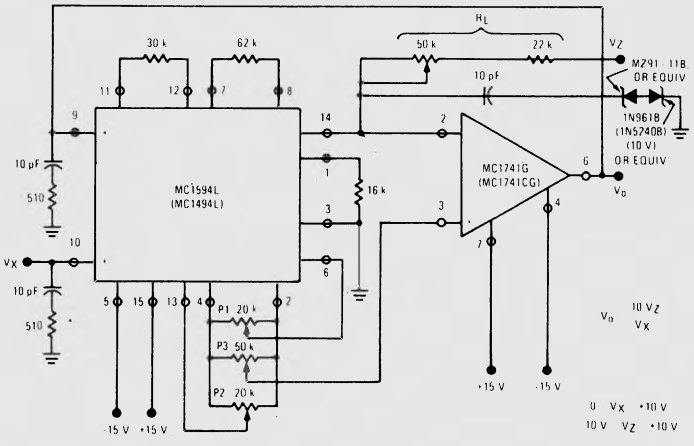
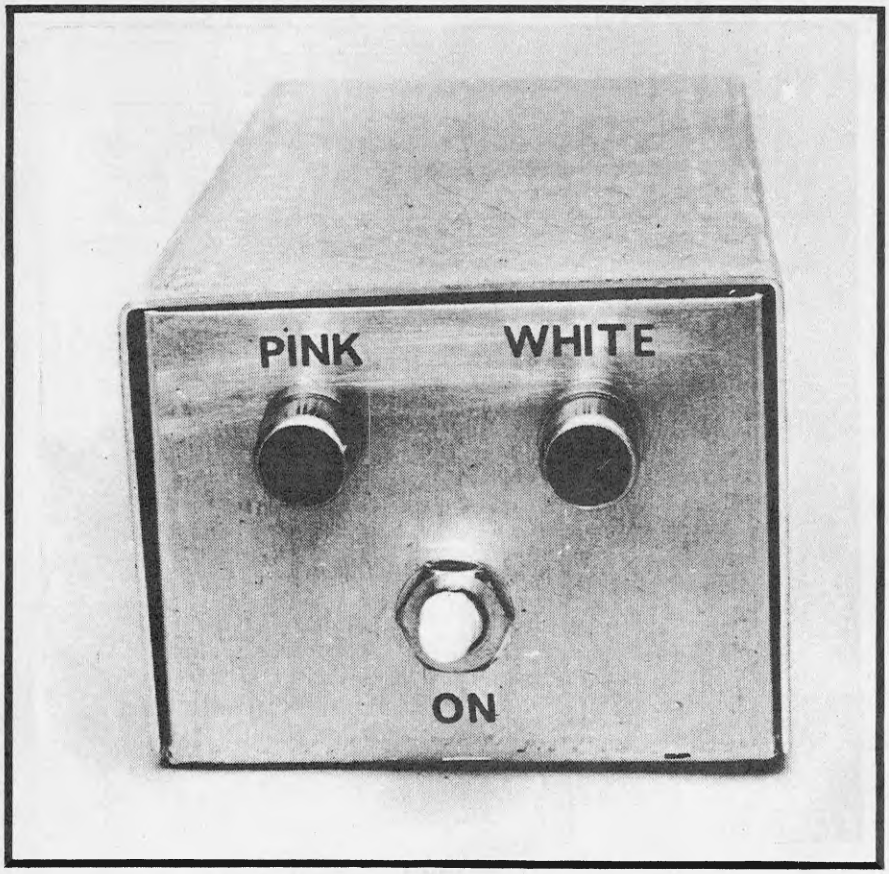


Fig. 10 Typical connection of a divide circuit. For the square root joins pin 9 and 10. Like the squaring circuits pin 6 can be connected to 0V and P1 deleted.



Audio noise generator



Simple circuit generates both white and pink noise.

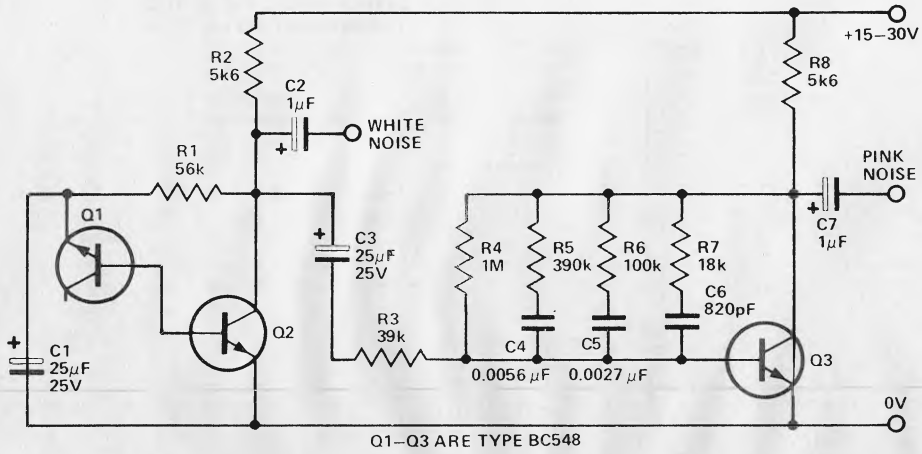


Fig. 1. Circuit diagram of the noise generator.

NOISE is generally an undesirable phenomena that degrades the performance of many measurement and instrumentation systems. It therefore seems strange that anyone should want to generate noise, but this is often the case.

Noise generators are often used to inject noise into radio-frequency amplifiers in order to evaluate their small signal performance. They are also used to test audio systems, and as random signal sources for wind-like effects in electronic music.

There are two commonly used noise source characteristics, 'pink' and 'white'. White noise is so called because it has equal noise energy in equal bandwidths over the total frequency range of interest. Thus, for example, a white noise source would have equal energy in the band 100 to 200 Hz to that in the band 5000 to 5100 Hz.

If white noise is filtered or modified in any way it is referred to as coloured noise or, often more specifically, as 'pink' or 'grey' noise. The term pink

HOW IT WORKS – ETI 441

In the days when vacuum tubes were in common use the most commonly used form of noise generator was a vacuum-tube diode operated in the current saturation mode. Nowadays noise generators may be very complex indeed. Highly complex digital generators which produce psuedo-random digital noise may cost many thousands of dollars. An example of a simpler type of digital noise source may be found in our synthesizer design (see International Music Synthesizer 4600 ETI December 1973). However for audio work of a general nature the most commonly used, and the simplest, method is to use a zener diode as a noise generator.

Transistor Q1 is in fact used as a zener diode. The normal base-emitter junction is reverse-biased and goes into zener break-down at about 7 to 8 volts. The zener noise current from Q1 flows into the base of Q2 such that an output of about 150 millivolts of white noise is available.

The 'zener', besides being the noise source, also biases Q2 correctly, and the noise output of Q2 is fed directly to the White Noise output.

To convert the white noise to pink a filter is required which provides a 3 dB cut per octave as the frequency increases. A conventional RC network is not suitable as a single RC stage gives a cut of 6 dB per octave. Hence a special network of Rs and Cs is required in order to approximate the 3 dB-per-octave slope required. Since such a filter attenuates the noise considerably an amplifier is used to restore the output level. Transistor Q3 is this amplifier and the pink noise filter is connected as a feedback network between collector and base in order to obtain the required characteristic by controlling the gain-versus-frequency of the transistor. The output of transistor Q3 is thus the pink-noise required and is fed to the relevant output socket.

PARTS LIST — ETI 441

R1	Resistor	56k	½W	5%
R2	"	5k6	½W	5%
R3	"	39k	½W	5%
R4	"	1M	½W	5%
R5	"	390k	½W	5%
R6	"	100k	½W	5%
R7	"	18k	½W	5%
R8	"	5k6	½W	5%
C1	Capacitor	25µF	25V	electro
C2	"	1µF	25V	electro
C3	"	25µF	25V	electro
C4	"	0.0056µF		polyester
C5	"	0.0027µF		polyester
C6	"	820pF		ceramic
C7	"	1µF	25V	electro

Q1-Q3 Transistor BC548, BC108 or similar
PC board ETI 441
CASE
BATTERIES
OUTPUT SOCKETS

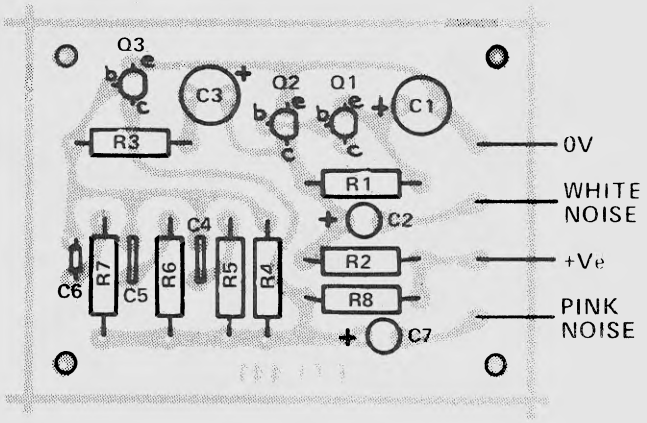
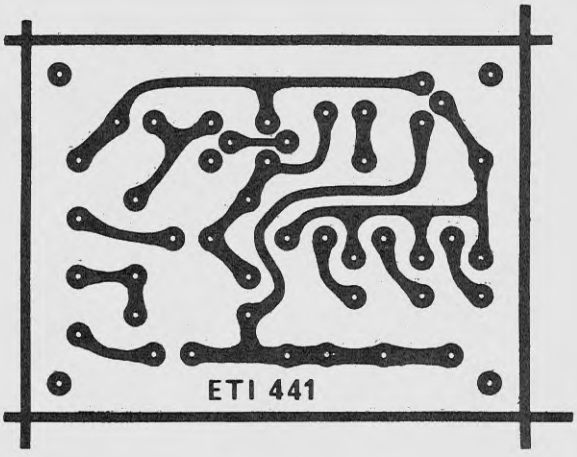


Fig. 2. Component overlay.



Printed circuit layout. Full size 67 x 49 mm.

noise should be restricted to the noise characteristic that has equal energy per percentage change in bandwidth. For example with true pink noise the energy between 100 Hz and 200 Hz should equal that between 5000 Hz and 10 000 Hz (100% change in both cases).

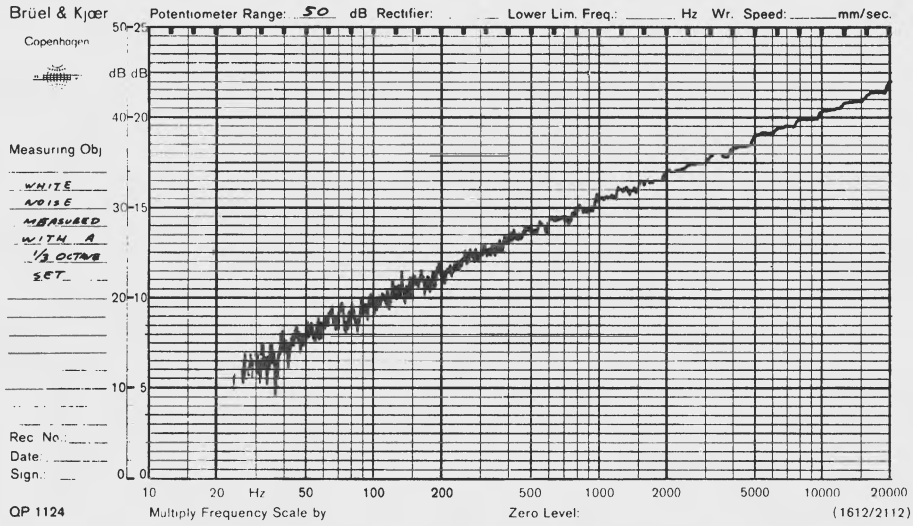
Pink noise therefore appears to have more bass content than does white noise, and it appears to the ear to have a more uniform output level in audio testing. To change white noise to pink noise a filter is required that reduces the output level by 3 dB per octave (10 dB per decade) as the frequency is increased. The ETI 441 Noise Generator is designed to provide both white and pink noise as required.

CONSTRUCTION

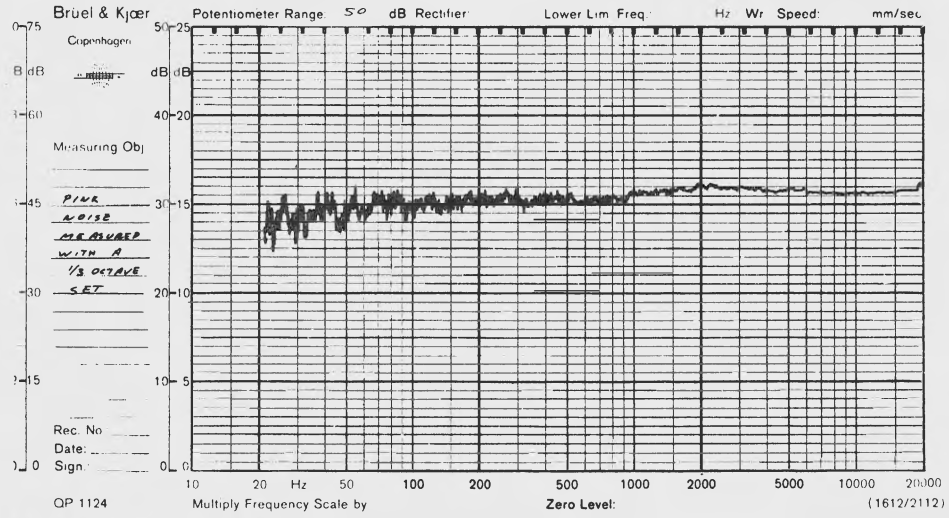
Construction is relatively simple and almost any of the common methods, such as Veroboard or Matrix board, may be used if desired. For neatness and ease of assembly it is hard to beat a proper printed-circuit board and for this reason we have provided details of a suitable board.

Almost any type of NPN transistor will do for the generator provided that the one used for Q3 has a gain of 100 or more. If BC548 type are used watch out for the two different pin connections used by different manufacturers.

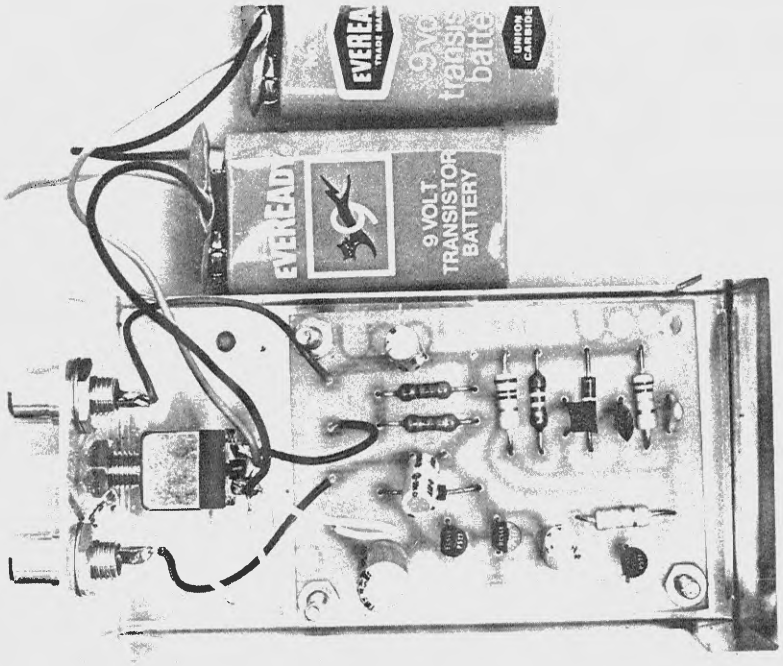
For use as a separate instrument in general experimentation the unit will need to be powered by a pair of nine-volt batteries. However if the unit is to be built into some other piece of equipment, as is often the case, any supply within the equipment which has an output of between 15 and 30 volts dc will be suitable.



Amplitude of white noise versus frequency as measured with a one-third octave filter set.



Amplitude of pink noise versus frequency as measured with a one-third octave filter set.



Internal layout of the generator.

Audio attenuator

This useful audio attenuator project for the experimenter provides 0-59dB attenuation in one dB steps.

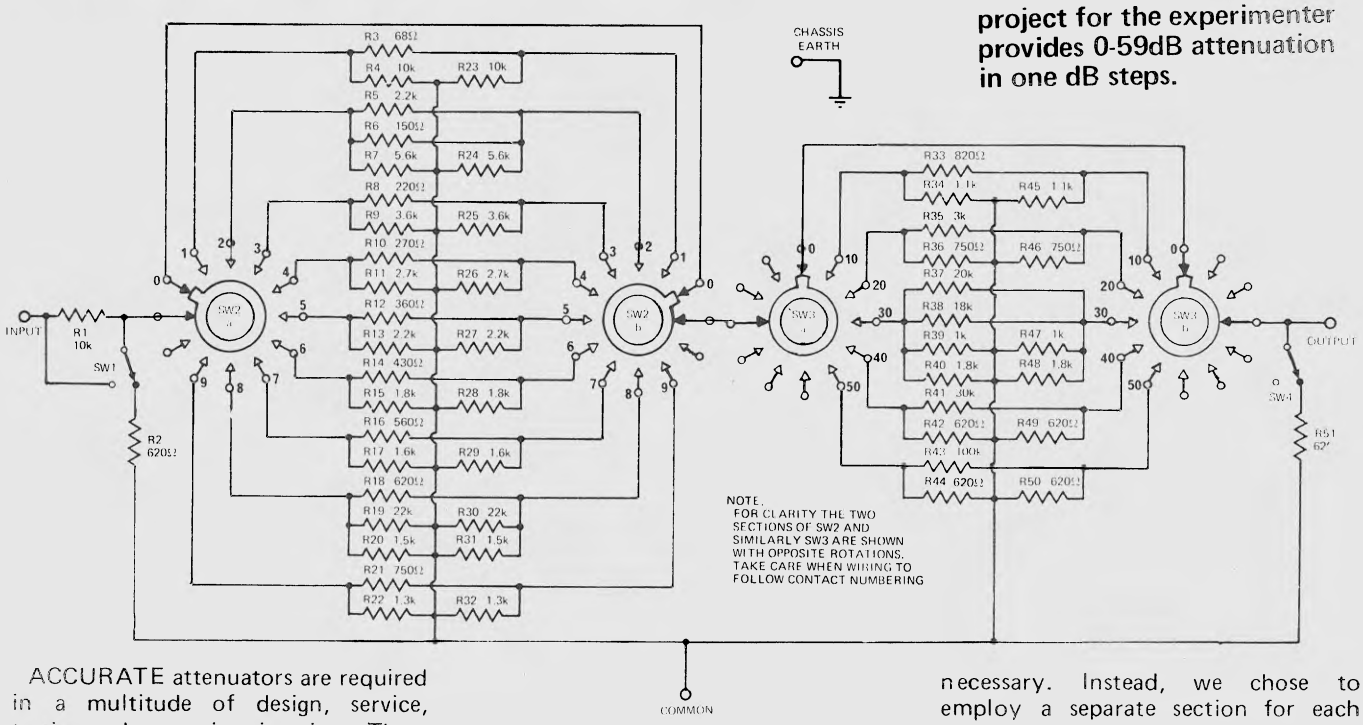
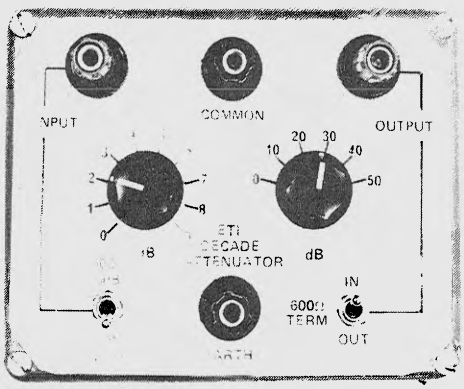


Fig. 1. Circuit diagram of the attenuator.

ACCURATE attenuators are required in a multitude of design, service, testing and measuring situations. These units are designed with varying degrees of accuracy and as many steps of attenuation as the designer feels necessary. They may be balanced or unbalanced and have whatever input and output impedances the designer requires.

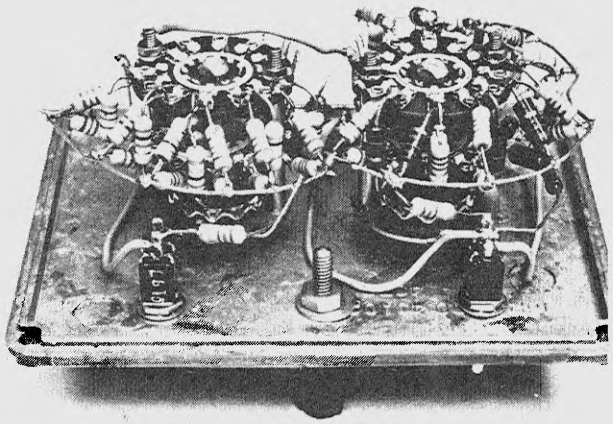
There are three common types of attenuator configuration, Pi, T or L. The latter is mainly employed where the output impedance is not required to be constant.

We have chosen Pi type sections for our unit. We could have connected the various sections in tandem to form a ladder attenuator, but this would have made more complex rotary switches necessary. Instead, we chose to employ a separate section for each step of attenuation, making only simple rotary switches necessary.



The input and output resistances of the unit remain relatively constant at 600 ohms over the full attenuation range. The input impedance can be changed to 10k by SW1 but an additional 30dB of attenuation is added. The output can also be terminated internally by SW4 when using a high impedance load such as a meter.

The maximum attenuation when the input and output resistances are set at 600 ohms is 59dB. There are ten 1dB steps from 0dB to 9dB, via a 10 position rotary switch, and a further six 10dB steps from 0dB to 50dB via a six position rotary switch, giving a



SPECIFICATION

Max attenuation	59dB
Resolution	1dB
Accuracy	±0.3dB
Frequency range	dc to 100kHz
Input impedance	600 Ω nominal
	10k switched (+30dB attenuation)
Output impedance	600 Ω nominal
Max input voltage	15 volt

Internal switched termination resistor for use with high impedance loads.

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PARTS LIST ETI 112

R1	Resistor	10k	2% ½W
R2	"	620Ω	" "
R3	"	68Ω	" "
R4	"	10k	" "
R5	"	2.2k	" "
R6	"	150Ω	" "
R7	"	5.6k	" "
R8	"	220Ω	" "
R9	"	3.6k	" "
R10	"	270Ω	" "
R11	"	2.7k	" "
R12	"	360Ω	" "
R13	"	2.2k	" "
R14	"	430Ω	" "
R15	"	1.8k	" "
R16	"	560Ω	" "
R17	"	1.6k	" "
R18	"	620Ω	" "
R19	"	22k	" "
R20	"	1.5k	" "
R21	"	750Ω	" "
R22	"	1.3k	" "
R23	"	10k	" "
R24	"	5.6k	" "
R25	"	3.6k	" "
R26	"	2.7k	" "
R27	"	2.2k	" "
R28	"	1.8k	" "
R29	"	1.6k	" "
R30	"	22k	" "
R31	"	1.5k	" "
R32	"	1.3k	" "
R33	"	820Ω	" "
R34	"	1.1k	" "
R35	"	3k	" "
R36	"	750Ω	" "
R37	"	20k	" "
R38	"	18k	" "
R39	"	1k	" "
R40	"	1.8k	" "
R41	"	30k	" "
R42	"	620Ω	" "
R43	"	100k	" "
R44	"	620Ω	" "
R45	"	1.1k	" "
R46	"	750Ω	" "
R47	"	1k	" "
R48	"	1.8k	" "
R49	"	620Ω	" "
R50	"	620Ω	" "
R51	"	620Ω	" "

SW1	Single pole change over minature toggle switch
SW2	2 pole 11 position rotary switch
SW3	2 pole 11 position rotary switch
SW4	Single pole change over minature toggle switch
Diecast box 4¾ x 3¾ x 2	
4	Terminals type L1568/15 or similar
2	Knobs

total of 60 steps from 0dB to 59dB. This range of attenuation is adequate for most purposes. Although further sections could be added, noise becomes a limiting factor in a simple attenuator such as this.

CONSTRUCTION

It is advisable to employ separate wafers for each switch pole. If the type of switch that has two poles on one wafer is employed, there may be problems at the high frequency end due to stray capacitance. This would be evident as spikes on the leading edges of high frequency square waves.

The common rail for each switch is a length of 18 gauge tinned copper wire formed into a ring to allow termination of the shunt resistors (R4, R23, R7 and so on). The series resistors are connected directly between the relevant switch contacts. Layout of the unit may be seen by the accompanying photographs. ●

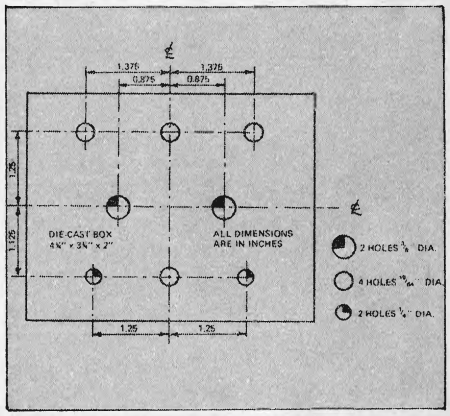


Fig. 2. Drilling details for the die cast box.

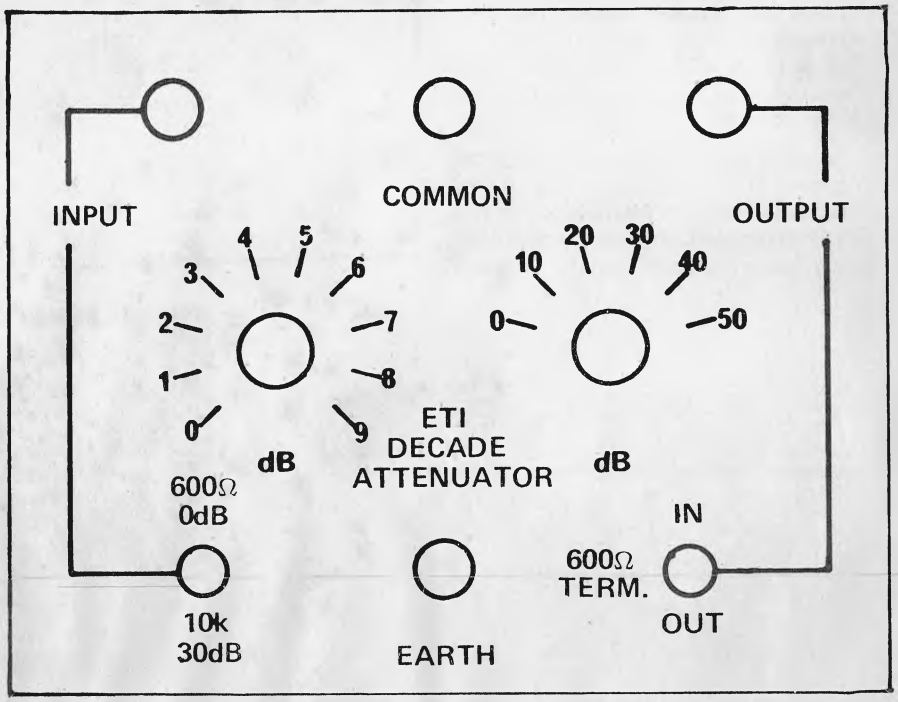


Fig. 3. Lettering and front panel artwork — full size.

0-40 V/5 A laboratory power supply Part 1

Here's a laboratory standard power supply featuring truly regulated output from zero to 40 volts capable of delivering a massive 5 A across the whole voltage range, plus current limiting variable from zero to 5 A. Two meters monitor voltage and current and regulator dissipation is reduced by employing an automatic transformer switching circuit.

David Tilbrook

IN APRIL 1976 we published the ETI-131 General Purpose Power Supply. This project could be built in two versions — 0-20 V/2.5 A or 0-40 V/1.25 A. It featured variable current limiting and had pretty close to lab-standard specs. A great many have been built since then and are to be found in development laboratories, service workshops, technical college and university labs and hobbyist's workshops.

Since that time, electronic technology has made considerable strides and the sort of things now being investigated by hobbyists and in electronics labs of all descriptions range much wider than they did when the ETI-131 was in vogue. It came to our notice that a lab-standard supply having 'expanded' specifications was in demand so we set out to investigate what sort of project would best meet that demand.

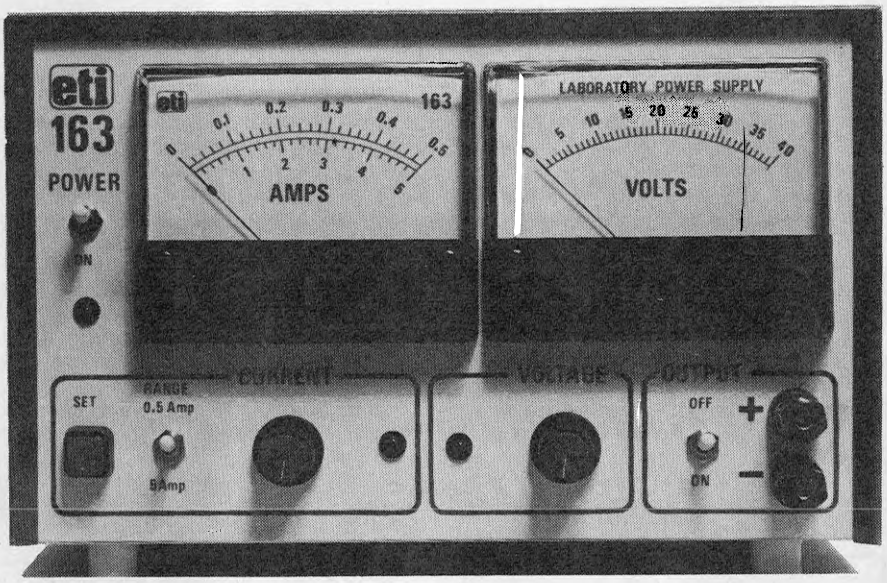
Following considerable discussion with both users and project suppliers, it was apparent that the most generally useful output voltage range would be about 0-40 V or 0-50 V and the required maximum current capability would be in the vicinity of 3-4 A or so. The next thing to do was to define 'lab-standard'.

Defining 'lab-standard'

An 'ideal' power source should provide the following: • a regulated voltage variable from zero to some chosen limit • no extraneous hum or noise on the output and none radiated from the supply • current-limit operation from zero to some chosen limit • simultaneous metering of current and voltage output • protection from short circuits on the output at any output setting.

In addition, handy 'operator features', such as indicators to show voltage and current mode operation, output and current-set switches, are desirable.

What sort of specifications would approach the 'ideal'? With sensitive high gain, dc control, audio or RF circuitry attached to the supply during circuit development or fault locating, you want to be sure that any problem experienced is not caused by some characteristic of the power supply. Hence, hum and noise are an important consideration. ▶



Power and performance. The completed supply looks smart, performs well and is economical to build — at around $150-$160.

SPECIFICATIONS — ETI-163 LAB. SUPPLY TABLE 1

Output voltage	0-40 V, variable
Output current	0-0.5 A, variable limiting 0-5 A, variable limiting
Output regulation	<50 mV at up to 2.5 A <100 mV up to 5 A
Ripple and noise	
voltage mode	<3 mV RMS
current mode	<10 mV RMS
Maximum output power	200 watts
Metering	
Voltage	0-40 V in 1 V divisions
Current	0-0.5 A in 20 mA divisions 0-5 A in 200 mA divisions

- **LED to indicate voltage mode operation**
- **LED to indicate current mode (limiting) operation**
- **Current-set switch provided for setting current limit value**
- **Output switch provided to isolate supply output**
- **Output terminals isolated from chassis**
- **Full output current available right up to 40 V**

A figure under 10 mV is a desirable goal, preferably less than 5 mV. Performance in the current-limit mode should be similar, but is not as critical a parameter.

As supply voltage variations can adversely affect some circuits, regulation of the output voltage over the whole variation range is paramount. It should remain virtually constant despite relatively large mains input voltage excursions and despite large variations in current drawn (up to the maximum). Regulation can be expressed as a percentage (with respect to full output) or as a voltage variation. The latter is preferred as it shows performance over the whole output variation range.

A regulation figure of 0.1% (100 mV in 100 V) is common for low current output supplies (up to 1 A), but 0.5% is more usual for high current supplies. That would be 250 mV for a 50 V supply.

Regulator techniques

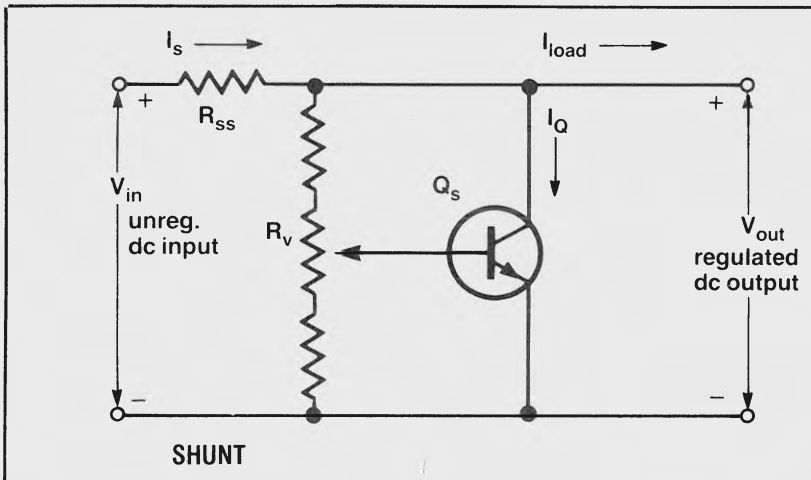
There are a number of basic techniques used to provide a regulated supply voltage. Choice depends on the application. The respective methods and their characteristics may be summarised as follows:

• **The shunt regulator.** This design is suitable mainly for low-power supplies — 15 to 20 watts. It has good regulation and is inherently short circuit proof. However, it dissipates the full amount of power it is capable of handling under no-load conditions.

Current-limit operation is not so easy to incorporate, but cost is low.

• **The series regulator.** Probably the most widely used technique. It is suitable for power supplies capable of delivering up to 200 watts.

Regulation, hum and noise performance is good, it's easy to arrange current-limit operation and cost is relatively low.



The shunt regulator. Fundamental circuit of a shunt regulator. As the load current (I_{load}) increases, the output voltage (V_{out}) tends to fall, reducing base current to Q_s. This, in turn, reduces the collector current (I_Q) of the shunt regulator, Q_s. The voltage drop across R_{ss} then decreases, maintaining the output voltage. As load current decreases, the opposite happens.

If the input voltage (V_{in}) increases, V_{out} tends to rise, increasing the base current to Q_s. This increases I_Q and the voltage drop across R_{ss} increases, maintaining the output voltage. If V_{in} decreases, the opposite happens.

Varying the wiper of R_v varies the collector current of Q_s, thus varying the voltage dropped across R_{ss}, setting the output voltage. Resistor, R_{ss} dissipates considerable power and Q_s dissipates the maximum output power under no load.

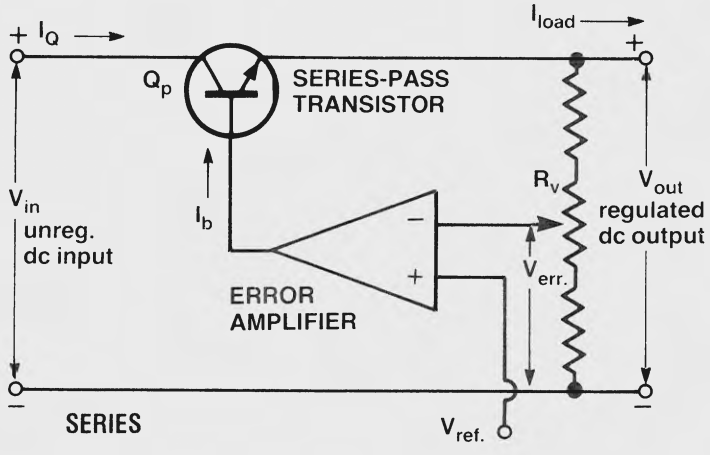
• **SCR regulator.** This technique is mainly suited for medium to very high power applications. The regulator has low dissipation and good regulation, but output noise and ripple are worse than for the series regulator and radiated switching 'hash' requires extensive shielding.

• **SCR pre-regulator and series regulator.** This combines the best features of the previous two and is best suited to medium to high power applications (say to several hundred watts).

An SCR pre-regulator provides a roughly regulated supply about five volts above the required output voltage, followed by a conventional series regulator. This keeps dissipation in the series regulator low. Cost is relatively high.

• **Switchmode regulator.** This technique is also used in medium to very high power applications. A series switching element stores energy in an inductor or capacitor, the on-time of the switching element being controlled to provide the required regulated output.

This technique keeps regulator dissipation low and regulation performance is good. With modern ICs purpose-built for the application, cost is about the same as a series regulator. However, noise and ripple on the output can be difficult to suppress and considerable wideband RF energy is radiated by the circuitry, necessitating careful and extensive shielding.



The series regulator. Fundamental circuit of a series regulator. As the load current (I_{load}) increases, the output voltage (V_{out}) tends to fall. This causes $V_{err.}$ to fall (the 'error voltage'). The error amplifier is operated as an inverting amplifier and thus, as $V_{err.}$ falls, the base current (I_b) to the series-pass transistor (Q_p) will rise. This causes the collector current (I_Q) of Q_p to rise, maintaining the output voltage. If I_{load} decreases, the opposite occurs.

If the input voltage (V_{in}) rises, the output will tend to rise, as will $V_{err.}$. This will produce a decrease in base current to Q_p, reducing I_Q, thus maintaining the output voltage. If V_{in} falls, the opposite will occur.

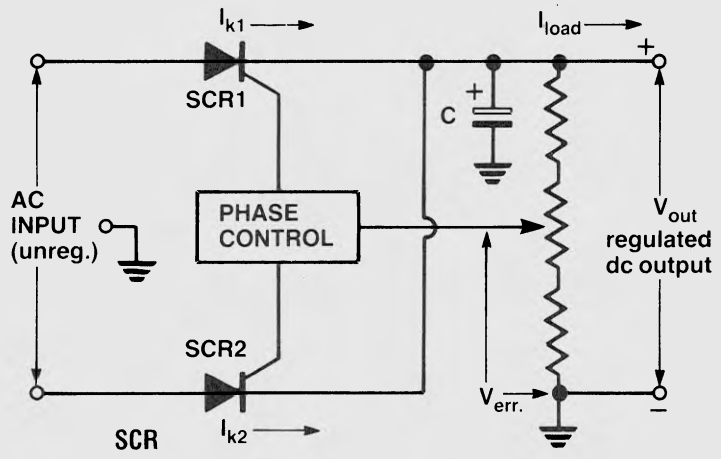
Varying the wiper of R_v varies $V_{err.}$, setting the output voltage.

Design features of this supply

I settled on an output voltage range of 0-40 V as this seemed to cover the great majority of supply requirements for circuit testing, development and fault locating. A maximum output current of 5 A was settled on for similar reasons. This results in an output rating of 200 watts, hence choice of an appropriate regulator technique was of paramount importance.

Two techniques were obvious contenders — series regulator and switchmode regulator. Previous experience with switchmode regulators made me wary that I could use one in a 'lab-standard' supply. The ETI-142 0-30 V/15 A supply (Feb. '79) employed a switchmode pre-regulator and a series regulator. Despite elaborate precautions, noise from the switchmode pre-regulator made it impossible to use this supply in the vicinity of, let alone connected to, sensitive circuitry. Pity, but a fact of life.

The inherent attractiveness of high efficiency — low dissipation is generally outweighed in this application. The necessity of elaborate screening and filtering brings problems of its own for constructors and increases costs.



The SCR regulator. Fundamental circuit of an SCR regulator. As the load current (I_{load}) increases, the output voltage (V_{out}) tends to decrease causing the 'error voltage' ($V_{err.}$) to drop. The phase control circuit then advances the triggering of the SCRs so that I_{k1} and I_{k2} and the average rectified voltage increases, maintaining the output voltage. If load current decreases, the opposite occurs.

If the ac input voltage rises, V_{out} tends to rise, causing $V_{err.}$ to rise also. The phase control circuit then retards the triggering of the SCRs, reducing the average rectified voltage, and maintaining V_{out}. The opposite happens if the ac input falls.

Varying the potentiometer varies $V_{err.}$, setting the output voltage.

I looked at the series regulator — and how to reduce the dissipation. For a 40 V output, dc input to the regulator would have to be around 50 V. At 5 A output into a short circuit, worst case dissipation would be around 250 watts! That requires *big* transistors and *lots* of heatsink.

As pre-regulators increased the cost and the noise problems, I had to find another way to reduce regulator dissipation and I hit on the idea of switching the transformer secondary.

Using several cheap ICs as comparators and a couple of relays, I could switch the rectifier across different transformer taps as the regulator output voltage was varied.

However, this technique had the drawback that a 'special' transformer would be required. If I could choose the output taps so that they were at generally 'useful' voltages, the transformer stood a good chance of becoming a 'stock' item. With this in mind, I chose the secondary taps to be 12 V, 24 V and 36 V.

The prototype transformer was wound up for us by Permatran of Melbourne. It is rated at 250 VA.

Astute readers will notice that basically, only two output taps are really required as the 12 V output could be selected by switching between the 24 and 36 volt terminations. However, using relay switching, it is possible under some circumstances to short part of the secondary with consequent disastrous results. The 'switching' tree employed avoids this possibility.

A separate low voltage and current dc supply is necessary to power the op-amps in the regulator and to provide a 5 V reference. In the prototype, I used a small 12 V/150 mA transformer — a stock item from most electronics suppliers — but a 15 V/200 mA winding may be available on the transformers obtained by suppliers of this project.

Worst case regulator dissipation for this supply is around 120 watts, a much more manageable figure than 250 watts. It occurs when the output current is 5 A at a voltage setting near 25 volts. At maximum dissipation, the heatsinks stabilise at a temperature of around 65°C.

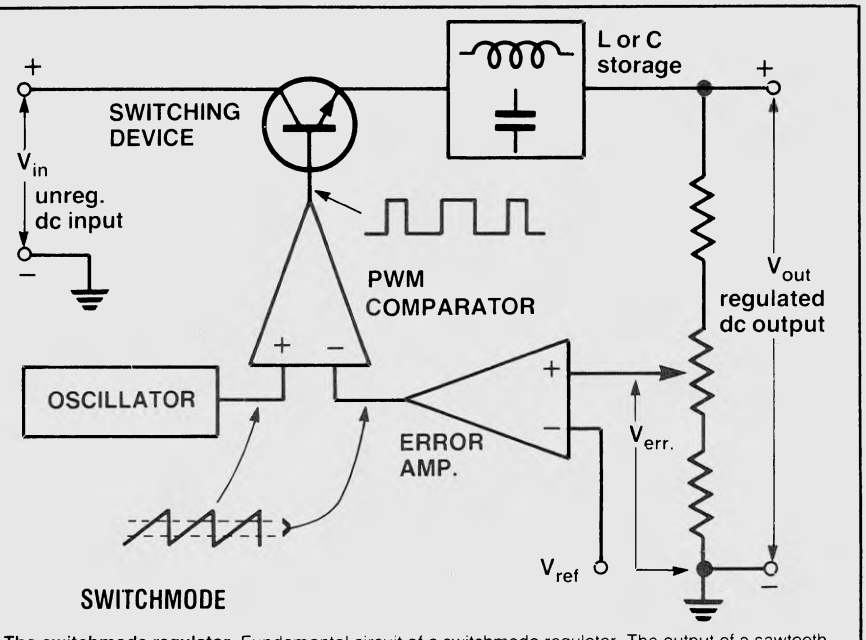
The regulator circuit is similar to the ETI-131 and employs two CA3130s for the voltage-mode and current-mode error amplifiers. A pair of MJ15003 high power NPN transistors connected in parallel are used for the series-pass element.

Another pair of CA3130s are used as comparators for the transformer secondary relay switching circuitry. These were chosen because their output can go right down to 0 V, ensuring the relay driver transistors turn off. The transformer taps are switched as the output voltage passes through about 12 V and about 25 V (these are adjustable over a few volts range). About a volt of hysteresis is added to the switching points so that the relays won't chatter when the output control is set on the switching point.

Separate meters are provided for indicating output voltage and current. There are two current-limit ranges — zero to 0.5 A and zero to 5 A. The point at which the supply switches from constant-voltage to current-limited (constant-current) output is fully variable across the two ranges.

A current-set pushbutton, which shorts the output terminals, is provided on the front panel and two LEDs indicate in which mode the supply is operating. A switch in series with the output allows you to isolate the supply from the load, without having to disconnect the supply or turn it off if you want the supply removed.

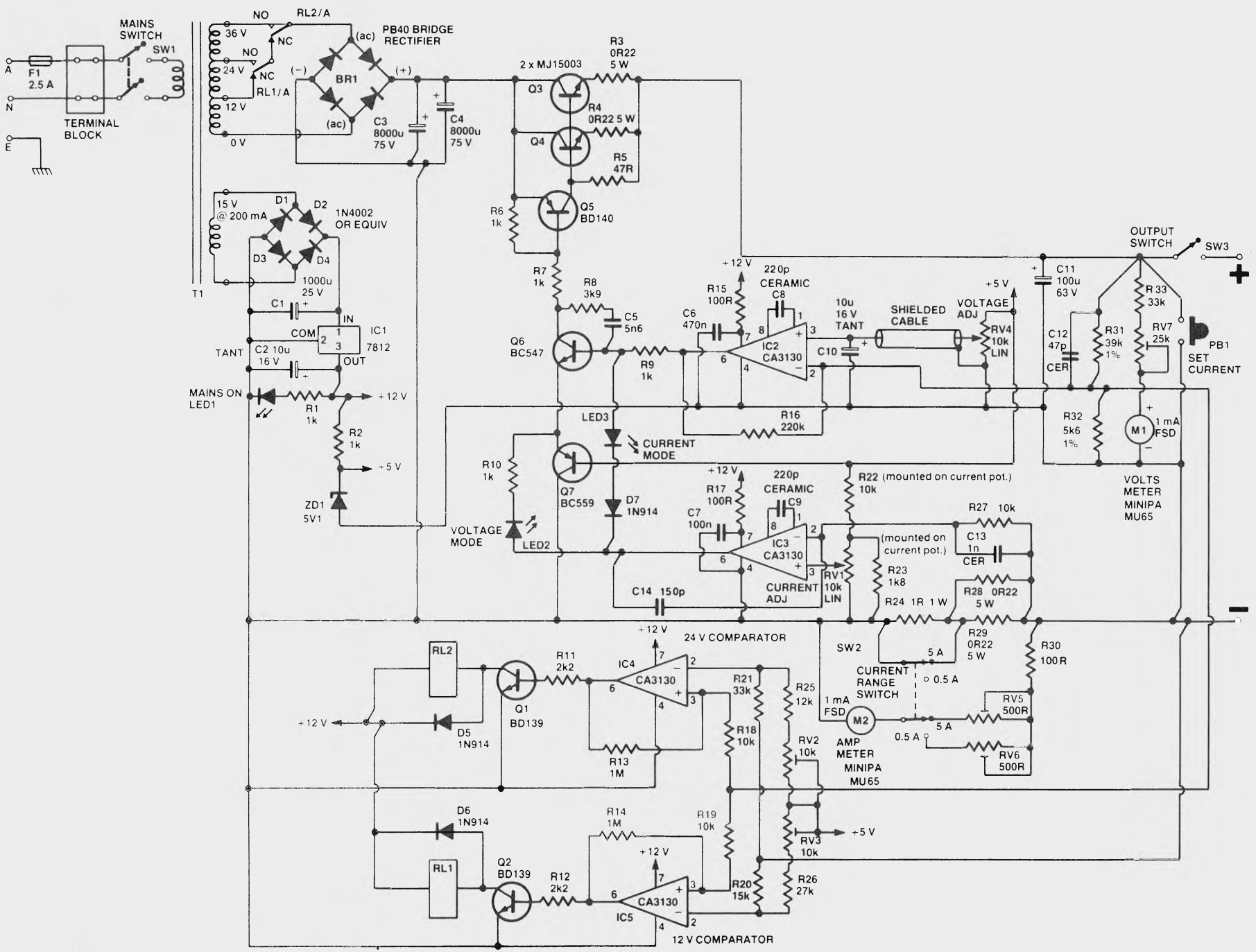
Performance turns out to be generally better than what was discussed as desirable for a lab-standard supply. See Table 1 for a complete run-down. ▶



The switchmode regulator. Fundamental circuit of a switchmode regulator. The output of a sawtooth oscillator and the output level of the 'error amplifier' are compared by the 'pwm comparator' which drives a switching device. The switching device turns on and off, storing energy from the unregulated input in a capacitor or inductor.

As the load current increases, the output voltage (V_{out}) will tend to fall as will the error voltage ($V_{err.}$). The output of the pwm comparator will turn on for a longer period for each cycle of the sawtooth. The switching device then conducts for a longer period, storing more energy in the L or C, maintaining the output voltage. As the output current decreases, the opposite occurs.

As the switching device is either hard on or fully off, it dissipates little power. Varying the potentiometer varies $V_{err.}$, setting the output voltage.


MAINS SWITCH
SW1
A
F1 2.5 A
N
E
TERMINAL BLOCK
NO
RL2/A
36 V
NC
NO
24 V
NC
RL1/A
12 V
0 V
PB40 BRIDGE RECTIFIER
(ac)
(-)
BR1
(+)
(ac)
C3 8000u 75 V
C4 8000u 75 V
T1
15 V @ 200 mA
D1
D2
1N4002 OR EQUIV
D3
D4
1000u 25 V
C1
IN
COM
IC1 7812
OUT
TANT
C2 10u 16 V
MAINS ON LED1
R1 1k
+12 V
R2 1k
+5 V
ZD1 5V1
2 x MJ15003
Q3
R3 0R22 5 W
R4 0R22 5 W
Q4
R5 47R
R6 1k
Q5 BD140
R7 1k
R8 3k9
C5 5n6
Q6 BC547
R9 1k
+12 V
220p CERAMIC C8
R15 100R
C6 470n
IC2 CA3130
10u 16 V TANT
C10
SHIELDED CABLE
VOLTAGE ADJ
+5 V
RV4 10k LIN
OUTPUT SWITCH
SW3
C11 100u 63 V
R33 33k
C12 47p CER
R31 39k 1%
RV7 25k
PB1
SET CURRENT
R32 5k6 1%
M1 1 mA FSD
VOLTS METER MINIPA MU65
R16 220k
LED3
CURRENT MODE
R10 1k
Q7 BC559
D7 1N914
LED2
VOLTAGE MODE
+12 V
R17 100R
C7 100n
220p CERAMIC C9
IC3 CA3130
R22 (mounted on current pot.) 10k
(mounted on current pot.)
R27 10k
C13 1n CER
R23 1k8
RV1 10k LIN
CURRENT ADJ
C14 150p
R24 1R 1 W
R28 0R22 5 W
R29 0R22 5 W
R30 100R
SW2
5 A
0.5 A
CURRENT RANGE SWITCH
1 mA FSD
M2
AMP METER MINIPA MU65
RV5 500R
RV6 500R
+12 V
24 V COMPARATOR
RL2
Q1 BD139
R11 2k2
IC4 CA3130
R21 33k
R25 12k
D5 1N914
R13 1M
R18 10k
RV2 10k
D6 1N914
R14 1M
R19 10k
RL1
Q2 BD139
R12 2k2
IC5 CA3130
R20 15k
R26 27k
RV3 10k
12 V COMPARATOR

The power supply employs a series regulator circuit with current limiting operation added. The 36 V secondary of the power transformer has taps which are switched in automatically by relays as the output voltage is adjusted so that power dissipation in the series-pass transistors is minimised.

An auxilliary 15 V secondary (or an auxilliary transformer) provides a supply for the reference voltage, the relays, relay drive circuitry and voltage and current feedback op-amps (IC2 and IC3).

The main power transformer (T1) secondary of 36 volts is rated to deliver 5 A and is tapped at 12 and 24 volts. The appropriate tapping is selected by the contacts of relays RL1 and RL2.

These relays are controlled by Q1 and Q2, which are driven by a pair of comparators formed by IC4 and IC5 and associated resistors — R13, 14, 18 and 19. These resistors give the comparators some hysteresis which ensures that the relays do not chatter when the output voltage is set exactly equal to one of the trip voltages.

Resistors R21, 25, 20 and 26 and the two preset pots RV2 and RV3 form adjustable potential dividers, driven from the +5 V reference line. These potential dividers set the trip voltages for the two comparators. The presets allow the actual trip voltage to be adjusted over a small range.

Relay RL1 will trip when the voltage is around 12 V, while RL2 will trip when it is around 25 V. In this way the series-pass transistors, Q3 and Q4, are supplied with enough voltage to ensure good regulation but not excess voltage which would cause unneccessary power dissipation.

The main voltage regulator error amplifier is formed by IC2, a CA3130 FET-input op-amp. This compares the voltage on its non-inverting input (pin 3) with that on its inverting input (pin 2) which measures the output voltage via the potential divider formed by R31 and R32. The non-inverting input is connected to the wiper of RV4 which allows the reference voltage at this point to be varied from 0 to 5 V.

The output of IC2 is connected via resistor R9 to the base of Q6 which, in conjunction with Q5, provides the necessary current to drive the bases of the parallelled series-pass transistors, Q3 and Q4.

The RC network R8-C5 serves to provide negative feedback around Q6 and helps to ensure stability by reducing the gain of the circuit at high frequencies.

The tantalum capacitor C10 serves to filter the reference voltage. This is important since the error amplifier uses this voltage to establish the output voltage. Any ripple at the non-inverting input of IC2 will be amplified and appear at the output of the power supply. Capacitor C12 serves a similar purpose as C5 and controls the high frequency phase shift in the negative feedback loop to prevent oscillation. C8 provides compensation for IC2.

The current-limit error amplifier is formed by IC3 and associated components — C14, C9, R17 and C7. Resistor R17 and capacitor C7 simply form a low pass filter to ensure a reasonably clean supply to the op-amp. C9 compensates the op-amp and C14 provides feedback to decrease overall gain of the feedback loop at high frequencies, thereby ensuring stability when the supply is operating in the current-limit mode.

The non-inverting input to IC3 is connected to an adjustable voltage reference formed by RV1, R22 and R23. The inverting input is connected via R27 to the negative output terminal of the supply.

This op-amp is, in effect, measuring the voltage drop across the series resistance of R24, R28 and R29. This voltage is proportional to the current drawn from the supply. The amount of series resistance is switchable by the current range switch, SW2.

In the 5 A range, R24 is shorted by the switch providing a series resistance of 0.11 ohms. If for example, a 5 A current limit was desired, the current adjust pot. (RV1) would be adjusted, after depressing the current-set pushbutton (PB1) to give 5 A, and this would result in a 0.55 V reference voltage appearing at pin 3 of IC3. This op-amp then compares the reference voltage to the voltage developed across the series resistance.

IC3 will provide the appropriate output to bring its two inputs to the same voltage and, since 5 A will cause a 0.55 V drop across the series resistance, the load current will be limited to 5 A.

This assumes that the output voltage has been set high enough to force more than the desired current through the load. If this is not the case, it is impossible for the current error amp. to correct what it sees as a gross error in the current. The reference voltage at pin 3 of IC3 will be greater than the voltage at pin 2 so that the output of the op-amp is forced hard against its positive supply rail, i.e: around 12 V. This forward biases LED2, which indicates that the supply is in voltage mode. i.e: the output is controlled by the voltage pot.

If, however, the reference voltage has been set high enough so that the current flowing in the load approaches that set by the current limit potentiometer, then the current error amp takes over control of the feedback loop and maintains the output so that only the required current flows in the load.

The voltage error amp (IC2) is then incapable of correcting the output voltage and its output swings hard against its positive supply rail (12 V) in an attempt to do so. This forward biases LED3 which indicates that the supply is in current mode. i.e: the output is controlled by the current adjust pot., RV1.

The voltage meter, M1, is a straightforward milliameter arranged to measure voltage via series dropping resistors R33 and the preset RV7 — the latter being for the purpose of calibration.

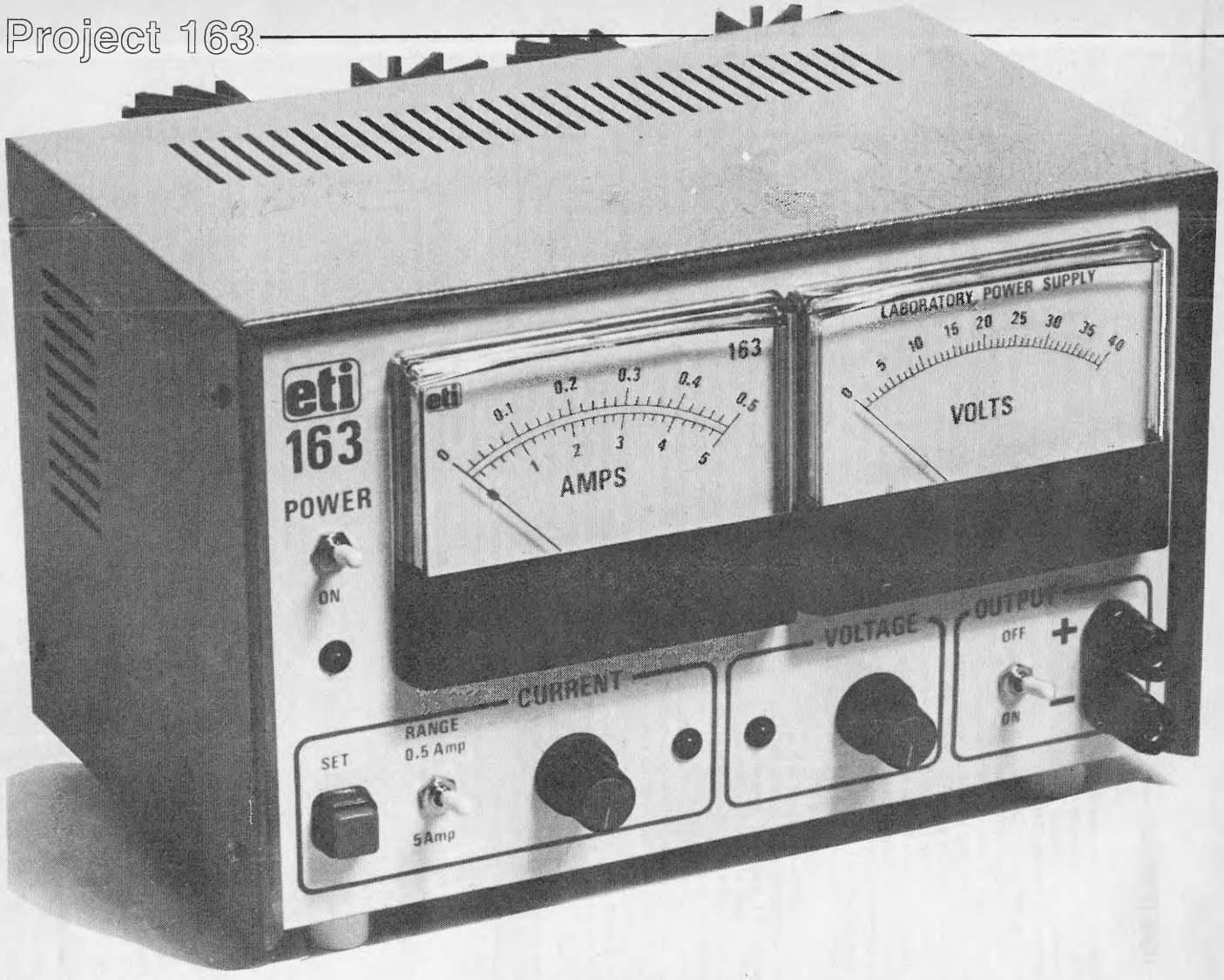
The current meter, M2, is effectively a voltmeter, measuring the voltage developed across the series resistance in the negative output line of the supply. Independent presets RV5 and RV6 are provided to allow calibration of the two output current ranges.

A bridge rectifier (BR1) and two 8000u/75 V capacitors (C3, C4) provide the main supply for the regulator.

The voltage and current error amplifiers must be supplied with a 12 V rail obtained independently of the main tapped secondary winding of the transformer. This can be supplied from an auxilliary winding on the main transformer or from a second small transformer. It should be rated, at a minimum, to deliver 12 V at 150 mA, but a rating of 15 V at 200 mA provides a greater margin.

Diodes D1 to D4 rectify this supply, C1 providing smoothing. This is then regulated by IC1 to 12 V. A 5V1 zener diode connected across this supply provides the 5 V reference used by the reference inputs of the voltage and current error op-amps, IC2 and IC3.

The 'mains on' LED indicator, LED1, is powered from the +12 V rail by the series dropping resistor, R1. The output switch, SW1 permits 'turning off ' the supply output without turning off the mains. ●



0-40 V/5 A laboratory power supply Part 2

Having introduced the project and the design technique chosen in Part 1, this part describes the construction and setting up.

David Tilbrook

Construction

This project is not recommended for beginners or inexperienced constructors. However, anyone with a modicum of electronics construction experience should be able to assemble this project with little difficulty.

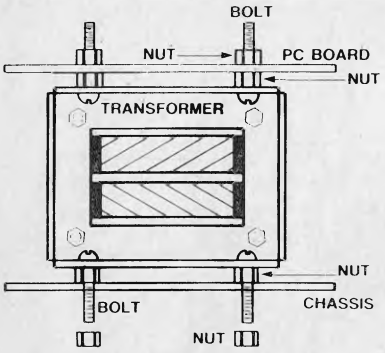
First off, no matter whether you've bought the components individually or purchased a kit, lay out all the parts and see that you have everything you need — including things like thermal compound, the right size nuts and bolts etc. Two basic grades of hookup wire are used to wire up the supply: ordinary 'light duty' (10 x 0.12 mm) hookup wire and 'heavy duty' (24 x 0.2 mm) or 'ultra heavy duty' (32 x 0.2 mm) wire. Those parts of the circuit carrying high currents are wired up with the heavy duty wire, as indicated in the wiring diagram.

The case we used is from K&W of Ballarat, Victoria, model C1066, supplied to us courtesy of Rod Irving Electronics. It is a popular and widely available case. Overall, it measures 255 x 165 x 155 mm and has a U-shaped aluminium chassis and hammertone blue steel lid with ventilation slots. It is supplied with four screw-on feet.

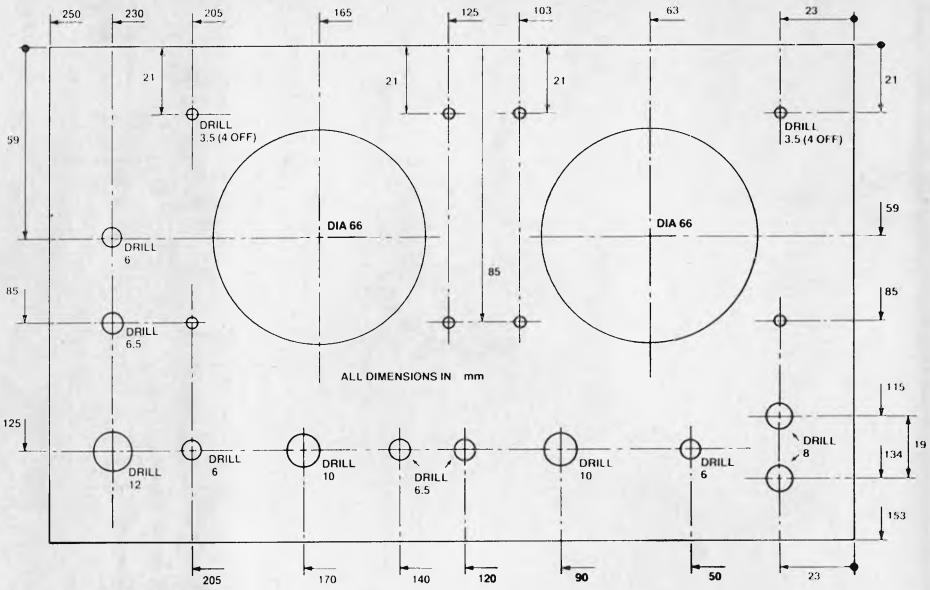
The chassis will need to be marked out and all holes drilled or cut out before any assembly can be commenced. Mark out the front panel according to the accompanying diagram. Centre punch all holes before drilling. Do a trial assembly of each component to see that they all fit and make any necessary adjustments.

No drilling diagrams have been given for the chassis bottom and rear panels as these will depend on the physical dimensions of the exact components used. Tackle the rear panel first. Place the two heatsinks side by side (see rear photograph), leaving room at the right for the mains fuse and power cord inlet. The two heatsinks we used were 150 mm lengths of black anodised radial fin type, manufactured and marketed by Rod Irving, No. HS3. There are similar types available. Any heatsink with suitable dimensions and rated dissipation of 1-1.3°C/watt will be perfectly adequate.

Holes will need to be drilled in the rear panel to accommodate the transistor mounting hardware, the transistor leads and bolts for securing the heatsinks. Having organised



Transformer and board mounting. How the power tranny, T1, and the pc board are mounted.



Get the drill? Drilling details for the front panel.

that, then locate the holes for the mains fuse holder and the power cord grommet — which should be a clamp type.

Mark out the case bottom next. Locate the mains transformer centrally between the sides and towards the rear, leaving no less than 15 mm clearance from the rear panel to the transformer bobbin. Four bolts are used to secure the transformer. Then locate and mark out the two filter capacitors, the bridge rectifier, the mains terminal block and earth bolt and the auxilliary 12 V (2851) transformer (if used). Make sure you don't foul the four case feet. Do a trial assembly to see it all fits correctly.

Remove burrs from all holes, then check that you've drilled all the required holes. Now stick masking tape across the rear (inside) of the front panel and spray paint the outside of it white. At the same time, remove the scale panels from the two meters, turn them over and spray paint them white, too. This ensures that the background for the Scotchcal labels is neutral as white Scotchcal is slightly translucent. Remove the masking tape from the chassis after the paint has dried.

Now the Scotchcal labels can be attached. Tackle the meter scales first. Peel off the backing along one edge for a little way then carefully align it on the edge of the scale panel and rub it down. Then peel off the backing further, rubbing down the Scotchcal carefully as you go. Take care not to get any, or many, bubbles under the Scotchcal label. If you do get some, they can be removed by rubbing them away towards the nearest edge. Work from the centre of the panel outwards.

Follow by applying the other meter scale Scotchcal and then the front panel. When the labels have been applied, cut out the holes using a modeller's scalpel or the like. Remember, a little patience prevents accidents. Re-assemble the meters.

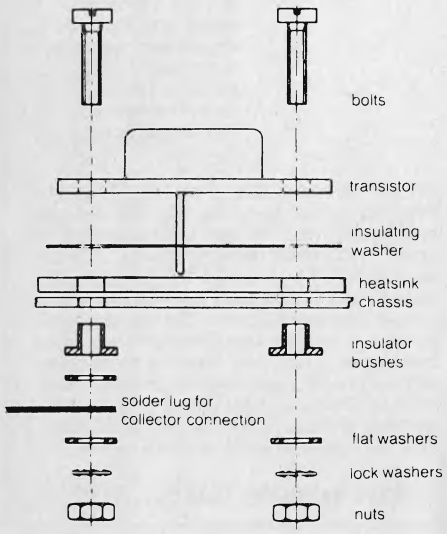
Now, you can mount all the front panel components — the meters, switches, output terminals, etc. Attach wires of appropriate length to them, as shown in the panel wiring diagram. Take care to use light duty and heavy duty hookup wire where indicated. Note that the lead from the voltage control potentiometer (RV4) to the pc board is a shielded cable. The shield braid is soldered only to the pot lug which connects to the 0 V output terminal and is left unconnected at the pc board.

Mount the rear panel components, but leave the mains cord off for the moment. Assemble the transistors to the heatsinks and chassis as indicated in the accompanying diagram. Attach wires to the transistors as per the wiring diagram.

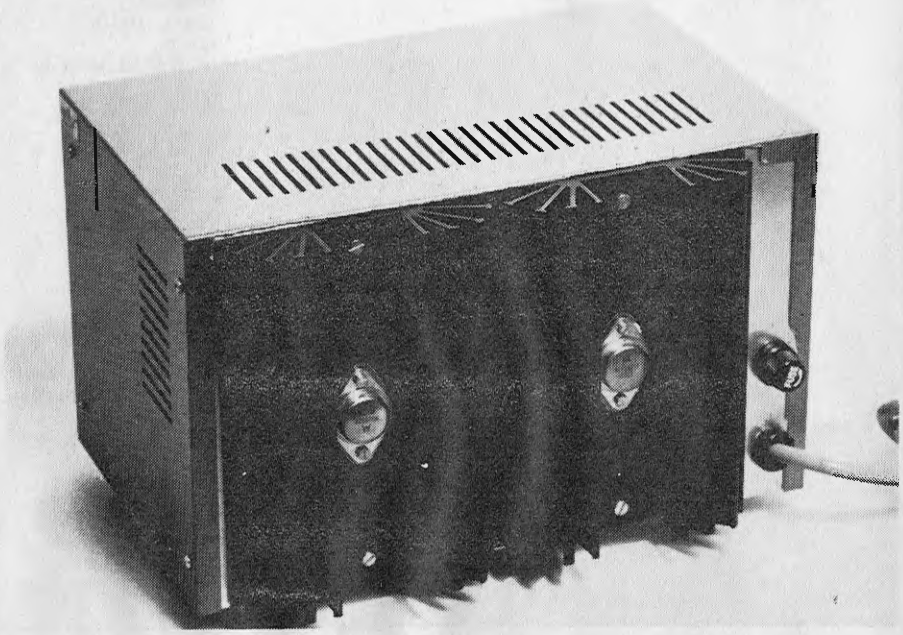
Mount the bridge rectifier and attach heavy duty leads of appropriate length to the lugs. Then mount the mains terminal block and the 2851 auxilliary transformer, if used. Wire the mains switch, mains fuse and mains terminal block. Sleeve the exposed fuse and switch connections. Mount the power transformer as per the diagram here, followed by the filter capacitors.

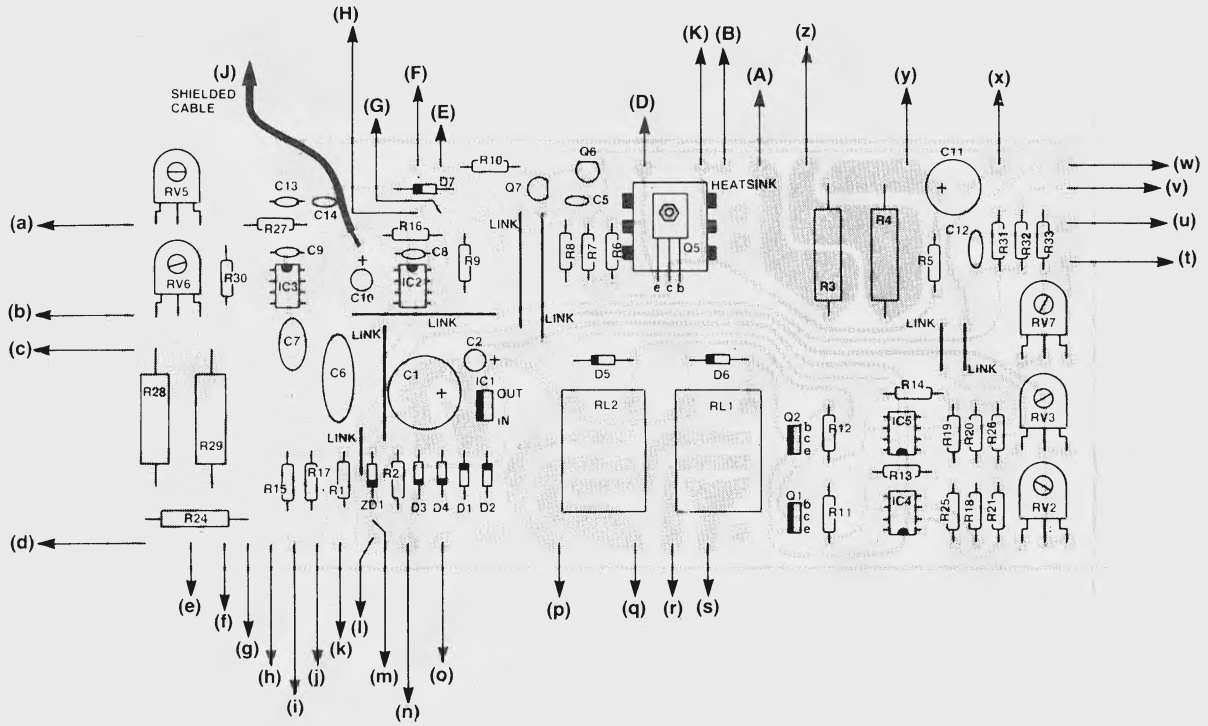
Assembly of the pc board can be tackled next. First, examine the tracks, looking for any breaks or hairline copper bridges between tracks. Check that all the holes are drilled and that they're of the correct size, particularly where the relays mount. ▶

Transistor mounting. How to mount the two power transistors, Q3 and Q4.



Rear view. Showing the components mounted on the rear panel. Note that the lip on the chassis lid needs to be cut away around the heatsinks and fuseholder.





If, or when, all's well with the board, commence assembly by soldering all the resistors and capacitors in place. Make sure you place the electrolytics and tantalums the right way round. The trimpots, note, are all laid flat on the board. Solder the pins in first, then carefully bend them so that the body lays flat.

The semiconductors may be soldered in place next. Check that each is correctly oriented before you solder it in place. If you wish, IC sockets may be used. Note that Q5, the BD140, requires a small heatsink. I used a Thermalloy No. 6073B, but any similar type that physically fits will do. Smear a little thermal compound on the metal face of the transistor before assembling it. No insulating washer is necessary.

The two relays can be mounted and soldered in place next, followed by all the pc stakes for terminating the leads to the components on the chassis.

The pc board bolts on top of the transformer. Note that provision has been made on the pc board for mounting holes to suit either the Permatran or the Ferguson transformer, whichever is used. It mounts on top of the transformer, as per previous diagram.

Referring to the wiring diagram, wire up the pc board. Route all the wires carefully. Check it thoroughly when you've finished. Last of all, wire in the mains cable. Make sure the earth (yellow/green) lead is the longest so that, should the cable be accidentally pulled out, the earth lead is the last to break. ▶

PARTS LIST — ETI-163

Resistors ..... all ¼ W, 5% unless noted
- R1, 2, 6, 7, 9, 10 ... 1k
- R3, 4, 28, 29 ..... 0R22, 5 W
- R5 ..... 47R
- R8 ..... 3k9
- R11, R12 ..... 2k2
- R13, R14 ..... 1M
- R15, R30 ..... 100R
- R16 ..... 220k
- R17 ..... 100R
- R18, 19, 22 ..... 10k
- R20 ..... 15k
- R21 ..... 33k
- R23 ..... 1k8
- R24 ..... 1R, 1 W
- R25 ..... 12k
- R26 ..... 27k
- R31 ..... 39k, 1%
- R32 ..... 5k6, 1%
- R33 ..... 33k
- RV1, RV4 ..... 10k/A panel mount pot.
- RV2, RV3 ..... 10k/A min. vert. trimpots
- RV5, RV6 ..... 500 R min. vert. trimpots
- RV7 ..... 25k min. vert. trimpot

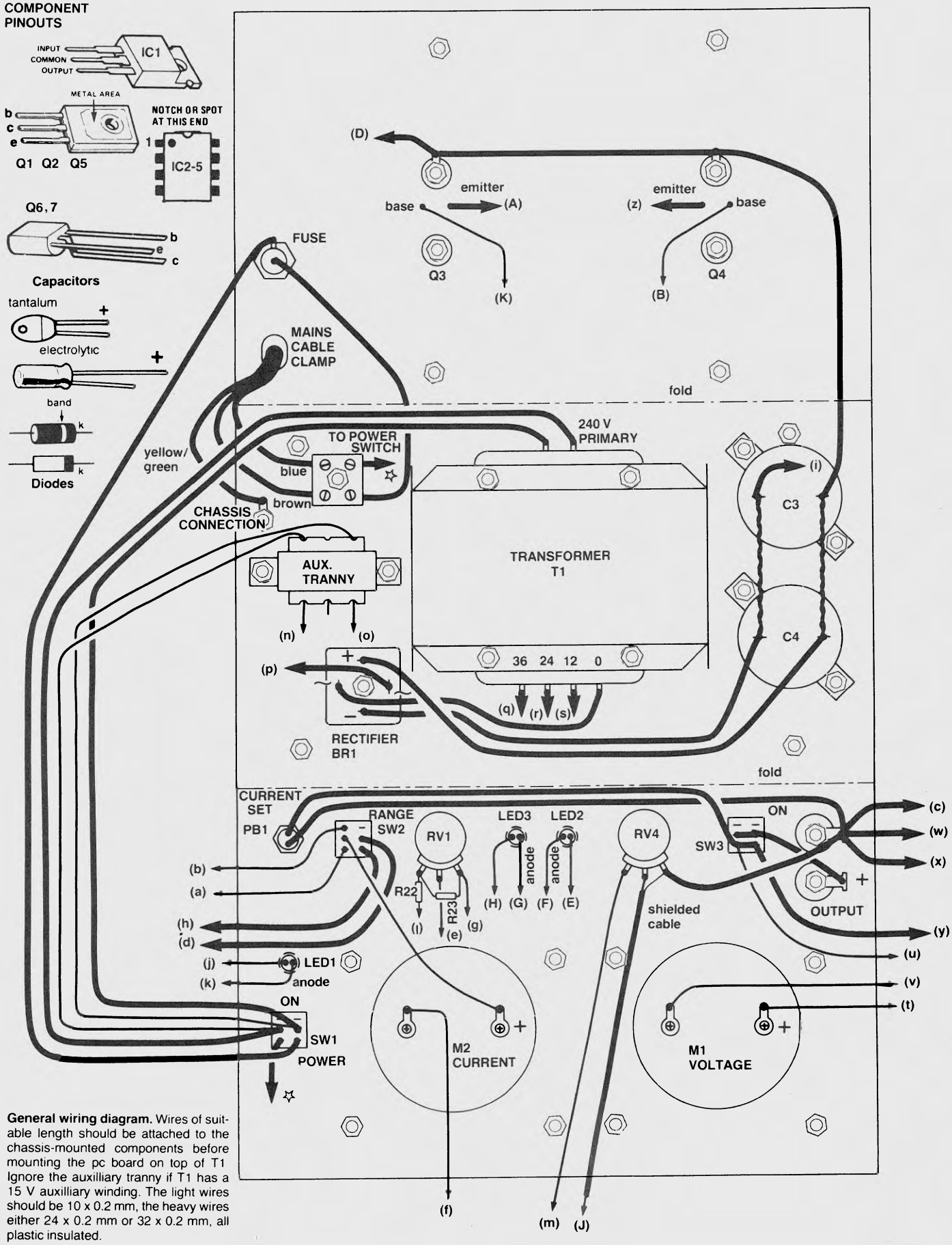
Capacitors
- C1 ..... 1000u/25 V single ended electro.
- C2, C10 ..... 10u/16 V tantalum
- C3, C4 ..... 8000u/75 V can electro.
- C5 ..... 5n6 greencap
- C6 ..... 470n greencap
- C7 ..... 100n greencap
- C8, C9 ..... 220p ceramic
- C11 ..... 100u/63 V single ended electro.
- C12 ..... 47p ceramic
- C13 ..... 1n ceramic
- C14 ..... 150p ceramic

Semiconductors
- BR1 ..... PB40, MDA2504, MDA3504 etc bridge rectifier
- D1, 2, 3, 4 ..... 1N4001, 1N4002, EM401, EM402 etc
- D5, 6, 7 ..... 1N914, 1N4148
- Q1, Q2 ..... BD139
- Q3, Q4 ..... MJ15003, MJ15024 etc
- Q5 ..... BD140
- Q6 ..... BC547, BC107 etc
- Q7 ..... BC559, BC159 etc
- IC1 ..... uA7812, LM7812 etc
- IC2, 3, 4 ..... CA3130
- LED1 ..... TIL220R red LED
- LED2 ..... TIL220Y yellow LED
- LED3 ..... TIL220G green LED

Miscellaneous
- F1 ..... 2.5 A or 3 A fuse, type 3AG, and bayonet holder (e.g: D.S.E. cat. S-4206 or similar).
- M1, M2 ..... Minipa MU65 1 mA meter movements, or similar.
- PB1 ..... SP momentary action pushbutton, 125 Vac/6 A contacts, D.S.E. No. S-1199 or similar.
- RL1, RL2 ..... DPCO heavy duty relays, 125 Vac/10 A contacts, 12 V coil (160 ohm), Fujitsu FRL-264D012/02CK (D.S.E. No. S-7140 or similar).
- SW1 ..... DPST miniature toggle switch, 240 Vac/1.5 A contacts or greater, D.S.E. No. S-1174 or S-1168, or similar.
- SW2, SW3 ..... DPDT miniature toggle switches, 240 Vac/5 A contacts, D.S.E. No. S-1168 or similar.
- T1 ..... transformer, 240 V primary, 250 VA rating, main secondary to deliver 36 V at 5 A or better, tapped at 12 and 24 V, with auxilliary secondary of 15 V at 200 mA (or additional 2851 12 V/150 mA transformer if 15 V secondary not available).

ETI-163 pc board; K&W case No. C1066; two heatsinks — Rod Irving No. HS3 150 mm long single-sided radial fin type black anodised, or similar (1 C/watt); one Thermalloy TO-220 heatsink 6073B or similar (for Q5); two heavy duty captive-head binding posts (one red, one black); one two-way terminal block; TO3 insulating components — two sets; one clamp grommet; mains cord and plug; Scotchcal labels for meter scales and front panel; short length of shielded cable; three LED mounts; hookup wire — light (10 x 0.12 mm) and heavy (24 x 0.2 mm or 32 x 0.2 mm); 6 BA and 4 BA bolts and nuts, solder lugs etc.

Price estimate $165 — $170



General wiring diagram. Wires of suitable length should be attached to the chassis-mounted components before mounting the pc board on top of T1 Ignore the auxilliary tranny if T1 has a 15 V auxilliary winding. The light wires should be 10 x 0.2 mm, the heavy wires either 24 x 0.2 mm or 32 x 0.2 mm, all plastic insulated.

Now you're ready for the traditional 'smoke test'.

Test and set-up

Set all the trimpots to mid-position and the current and voltage controls a quarter-turn from minimum. Set the current range switch to 0.5 A and the output switch on. Plug the mains cord in and switch it all on.

The mains LED should come on, along with the voltage mode LED. The volts meter should read forwards, somewhere on the low end of the scale. If you don't get these indications, switch off and check for a wiring error (make sure you've a fuse in the fuseholder!).

Using a multimeter, check the voltage across the main filter capacitors (C3-C4). It should read around 17.5 V (with respect to the supply's negative output terminal — all readings are quoted with respect to this point). Check the voltage at pin 1 (in) of IC1 (i.e: at cathodes of D2-D4). This should be around 17.5 V if you're using the 12 V auxiliary transformer, or around 21 V if your main transformer has a 15 V auxilliary winding. Then check the output of IC1 (pin 3). It should be very close to 12 V. Check the voltage on the cathode of ZD1. It should be very close to 5.1 volts. No other voltages will tell you very much at this stage. If you don't get the correct readings switch off and check wiring and component placement. Correct any errors.

If all's well, advance the voltage control until you hear RL1 'click' on. The voltage on the positive terminals of C3-C4 should then be around 36 V. Advance it further until RL2 clicks on and the voltage on the positives of C3-C4 should rise to about 54 V or so.

Now check the voltage across the output terminals. Vary the voltage control over the full range and ensure that you can vary it right from zero volts to a little over 40 V. We'll get around to calibrating the meter later.

The current-limit operation can now be checked. Set the output switch off. Connect your multimeter directly across the output terminals. Set it to the 5 A or 10 A range. Ensure the supply's current range switch is set to 0.5 A. Set the voltage control back to about a quarter-turn from minimum. Throw the output switch on. The voltage mode LED should go off and the current mode LED should go on. (This should also occur when the voltage control is set at minimum.) See that the multimeter reads a low current. If it doesn't, you've got the current range switch upside down.

Set the multimeter to a convenient scale (1 A or 2 A). Turn the current control around to maximum and see that the multimeter reads around 0.6-0.7 A. Now set the multimeter to the 10 A scale and the current range switch to 5 A. The multimeter should read between 6 A and 7 A.

If all's well, the two meters can now be calibrated.

First, the volts meter. With the multimeter still connected to the output terminals, set it to a convenient scale so that you can accurately read 20 V. Adjust the voltage control to obtain 20.0 V on the multimeter. Now adjust RV7 so that the volts meter on the project also reads precisely 20 V. Then set the voltage to read 5 V on the meter and check that the output's within ;0.25 V.

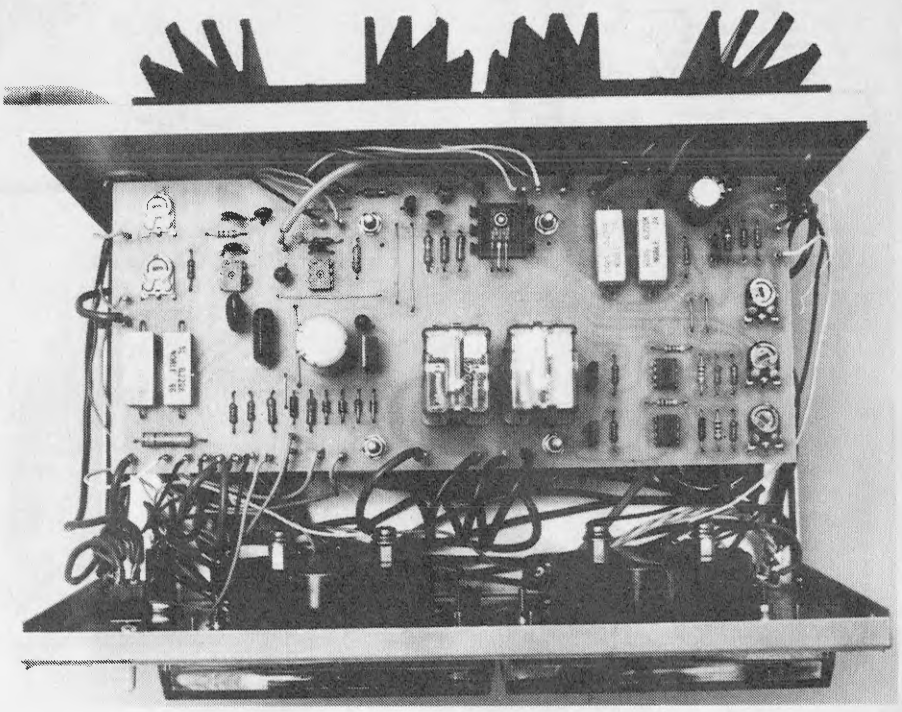
I have done this because many devices, TTL ICs and op-amps in particular, require accurate supply voltages and most are driven from supplies of less than 20 V. With TTL ICs a supply in excess of 5.5 V can destroy the device. Calibrating the meter at 20 V ensures that the meter accuracy at the low end is sufficient to obviate problems. If it's a volt or two out on the 20-40 V end of the scale, it doesn't matter so much.

To calibrate the current meter, first set the supply's output switch off. Set the current range switch to 0.5 A and set both the voltage and current controls about a quarter-turn off minimum.

Switch on the supply output and adjust the current control to obtain a reading of 500 mA on the multimeter. Then adjust RV6 so that the current meter reads full scale. Set the multimeter to the 5 A or 10 A scale and the current range switch to 5 A. Set the current control so that the multimeter reads 5.00 A and adjust RV5 so that the current meter reads full scale.

The current control has to be re-adjusted when switching from 0.5 A to 5 A as the current sensing resistor for the 5 A range is not exactly 0.1 ohms, being made up from two 0R22/5 W resistors in parallel which are the only ones generally available. Some tolerance in values will account for a difference in any case.

Now the relay 'trip' points can be set. Turn RV2 and RV3 fully anticlockwise. Set the output voltage to something less than 10 V. You can do this adjustment using either the project's volts meter or your multimeter connected across the output terminals.



Top down view. Inside the lab. supply, showing board mounting and wiring.

Slowly advance the voltage control until the output is 12.5 V or thereabouts. Then rotate RV3 clockwise until RL1 just clicks in. This trimpot gives a trip point range of about 3 V from about 11 V to about 14 V. You may notice the output actually drop a few hundred millivolts when RL1 pulls in, but this is of no consequence.

Having done that, slowly advance the voltage control until the output voltage reaches about 25.5 V. Then rotate RV2 clockwise until RL2 clicks in. The output will drop a few hundred millivolts when you do this, but as before, it's unimportant. This trimpot has a trip point range of about 6 V, from roughly 24 V to about 30 V.

That's it! Now you can screw the lid down and put your ETI laboratory supply proudly on the workshop shelf.

Tips on using it

Always set up the power supply with the output switch *off*. Set the output voltage to what is required by the circuit you're working on. Then set the current limit range switch to the appropriate range, press the current set button and adjust the current control so that the current meter reads a little above what you expect the circuit to draw. Don't forget to allow for relay turn-on currents, lamps, indicators and etc in the circuit.

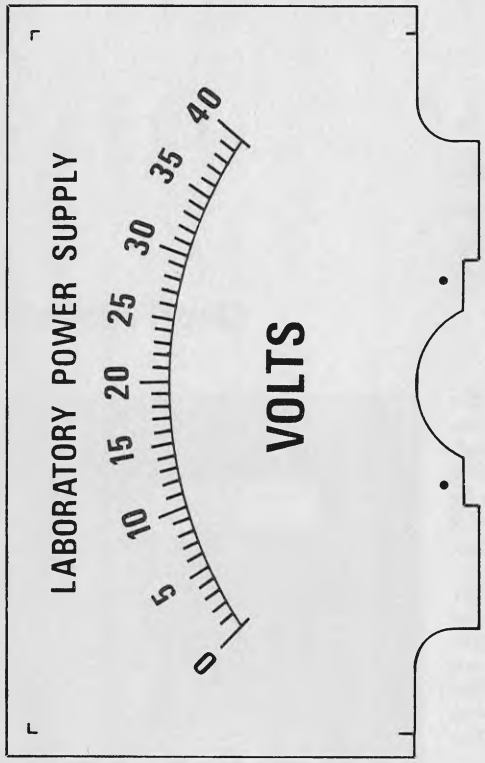
With straight CMOS circuits, even those with a dozen or more ICs, a current limit of 100-150 mA is a good safe limit.

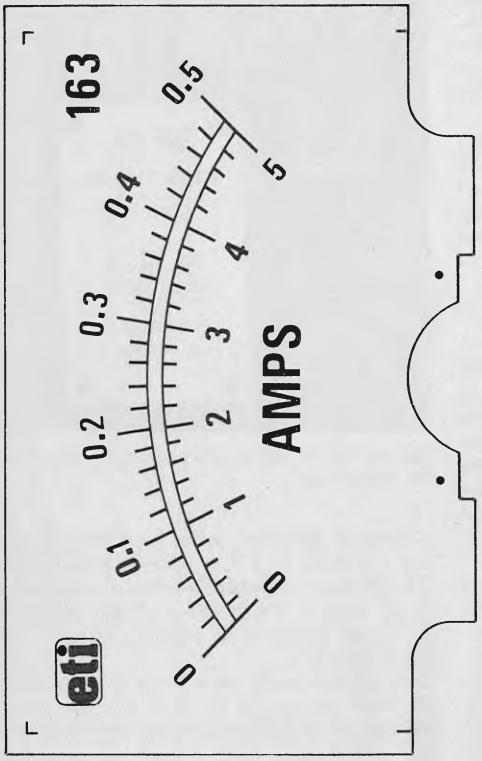
Beware of circuits which may draw peak currents several times the average current and set the current limit to take this into account (i.e: audio amplifiers, pulse circuits).

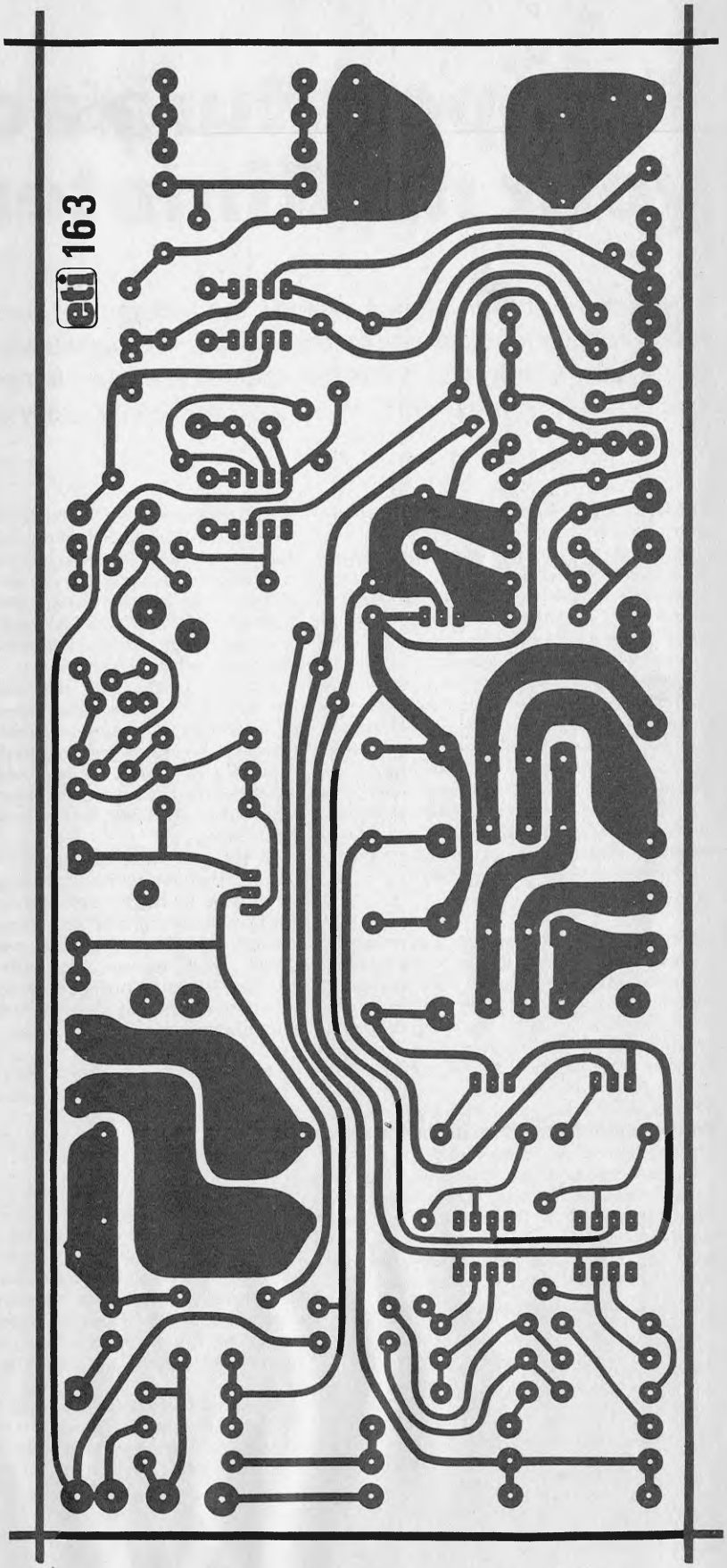
With a little experimentation and experience, you'll soon learn how to set up and effectively use the ETI-163 Lab. Supply. ●

Artwork. Here is full-size artwork for the pc board and the two meter scales. Unfortunately, the artwork for the front panel is too large to reproduce here. A photostat can be obtained by sending us a stamped-addressed A4-sized envelope.

You can obtain 1:1 positive or negative film of all the artwork for this project for $15 post paid from **ETI-163 Artwork, ETI Magazine, P.O. Box 21, Waterloo NSW 2017.** Make cheques or money orders payable to 'ETI Artwork Sales' and ensure you ask for **positive** or **negative** film, as you require.







Temperature adaptor for your multimeter

This simple add-on project extends the functions of your multimeter to the measurement of temperature. It is particularly suited to digital multimeters. It can be used to measure temperature over the range from −55°C to +150°C with an accuracy of 0.5°C or better.

Geoff Nicholls

IT IS SURPRISING how useful an 'electronic thermometer' can be in an electronics workshop or laboratory. Temperature measurement is a rarely-included function on modern multimeters, however. Measuring temperature in a chemistry or physics lab is commonplace, and the same should be so in an electronics lab, but rarely is.

Component temperature rise, or the actual operating temperature of a device, can be an important parameter in a circuit — no matter whether the component's a resistor or a transistor. The performance of heatsinks can be assessed using temperature measurements.

When fault-finding or servicing equipment, thermal problems can be quickly sought out and identified by temperature measurement. And that's just a few applications!

Sensors

There are a number of ways to measure temperature electrically or electronically. Thermocouples, which consist of two dissimilar metal wires bonded together, have long been used. The junction of the metals generates a small voltage that is proportional to the junction temperature. The voltage output is non-linear with changing temperature. Thermocouples are generally used for temperature measurement at high temperatures and over extremely wide ranges.

The resistance of semiconductor material varies considerably with temperature and this is exploited in 'thermistors'. The variation is non-linear, but thermistors have been used for temperature measurement where accuracy and linearity are not important.

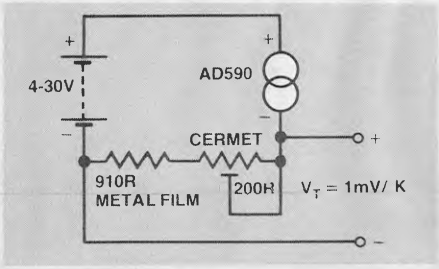


Figure 1. Simple thermometer with +/− 2°C accuracy.

Any semiconductor junction will exhibit temperature dependence of the forward conduction voltage. For silicon junctions, which have a forward conduction voltage of around 600 mV, the junction voltage will vary by typically −2.2 mV/°C at a forward current of around 250 uA, and this is generally linear over quite a wide range.

Silicon diodes and the base-emitter junction of silicon transistors are often used in temperature sensing and control applications. Accuracy and repeatability are generally very good. We described a digital temperature meter which employed a silicon diode sensor (ETI-589) back in the December 1977 issue.

However, a number of specially-constructed ICs are available which have been designed to provide a highly accurate and linear temperature-to-current or temperature-to-voltage output over a wide temperature range. Such devices are unrivalled for accuracy, linearity and speed of response.

I chose the Analog Devices' AD590 which is available in two package styles — a TO-52 'can' and a tiny ceramic flat pack — and several accuracy grades. It is distributed by Parameters Pty Ltd, 41 Herbert St, Artarmon NSW 2064. (02)439-3288.

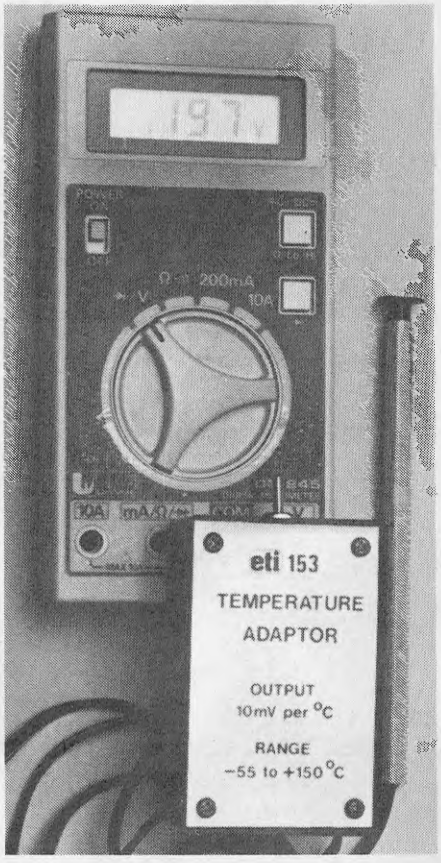
The AD590

The AD590 is a two-terminal integrated circuit temperature transducer which produces an output current proportional to absolute temperature. For supply voltages between +4 V and +30 V the device acts as a high impedance, constant current regulator passing 1 uA/°K. Laser trimming of the chip's thin film resistors is used to calibrate the device to 298.2 uA output at 298.2°K (+25°C).

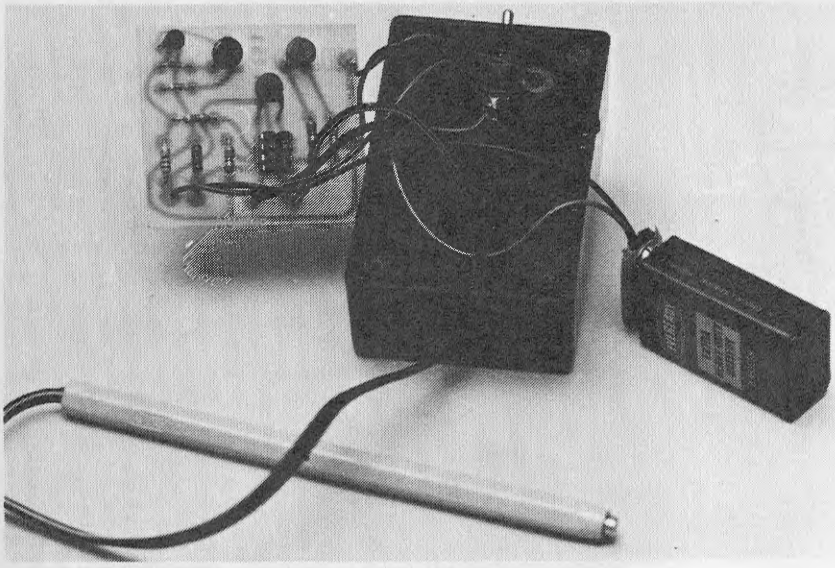
The device is particularly useful in remote sensing applications. The device is insensitive to voltage drops over long lines due to its high impedance current output. Any well-insulated twisted pair is sufficient for operation hundreds of feet from the receiving circuitry.

Superior interference rejection results from the output being a current rather than a voltage. In addition, power requirements are low (1.5 mWs « 5 V « +25 C), making the AD590 easy to apply as a remote sensor. The high output impedance (>10M) provides excellent rejection of supply voltage drift and ripple.

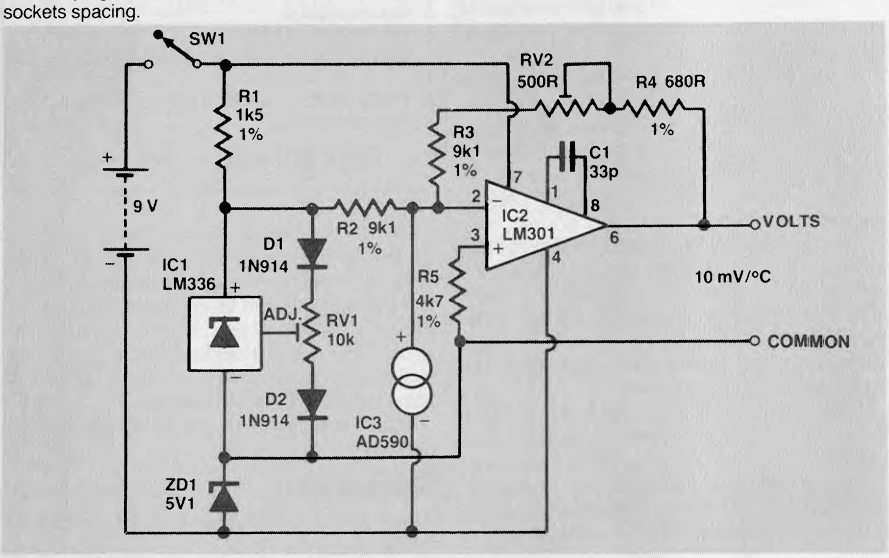
It is electrically durable, withstanding a forward voltage up to 44 V and a reverse voltage of 20 V. Hence, supply irregularities or pin reversal will not damage the device.



And it's 19.7°C! Our adaptor plugged into one of the lab. multimeters.



Simplicity. Construction is quite simple and all the electronics fits neatly in a small jiffy box. The tops of the banana plugs can just be seen. These are spaced at 19 mm ('GR' spacing) or to suit your multimeter input sockets spacing.



HOW IT WORKS — ETI-153

The AD590 temperature transducer, IC3, requires a voltage to be applied across it, developing a current that is directly proportional to absolute temperature with a precision sensitivity of 1 uA/°K. This is amplified by an op-amp, employed here as a current-to-voltage converter that provides an output of 10 mV/°C. As zero Kelvin is 273 degrees below zero Celsius, an 'offset' has to be provided for the output to be proportional to the Celsius scale. This is achieved by running the op-amp input at 'virtual ground' and supplying the AD590 sensor from a negative supply rail. Thus, at 0°C, the output will 0 V.

IC1 is a precision voltage reference (LM336) that maintains 2.49 V between its +ve and −ve pins. Two silicon diodes, D1 and D2, and a cermet (high stability) trimpot, RV1, allow the reference voltage to be 'trimmed'. This is normally done to minimise the temperature coefficient of the LM336, however, I have used it to provide trimming of the offset of Celsius zero from absolute zero.

Zener diode D3 provides a negative supply rail for the AD590 temperature transducer (IC3). The voltage obtained is around −4.5 V as the 5V1 zener is operated at a current of about 1 mA, set by the value of R1. The zener in the prototype was rated at 400 mW. If a 1 W type is used, R1 should be reduced to 1k.

IC2 is used in 'virtual ground' mode as a current-to-voltage converter. Its operation can be understood by remembering that IC2 is an op-amp and to a good approximation has infinite gain and infinite input impedance. A negative feedback path, formed by R3-R4-RV2, acts to maintain the inverting input (pin 2) at the same potential as the non-inverting input (pin 3). i.e: at 0 volts. Although very little current flows into pin 2 of IC2, it is kept at 0 V by the feedback action.

The AD590 connects to pin 2 of IC2 (inverting input) and acts as a current sink, passing 1 uA/°K. The reference, IC1, supplies a current of 273 uA through R2, which can be trimmed by RV1. Thus, the current through the feedback resistors is equal to the absolute temperature minus 273, in microamps, and results in an output voltage of 10 mV/°C when RV2 is set to provide the 'scale factor' required.

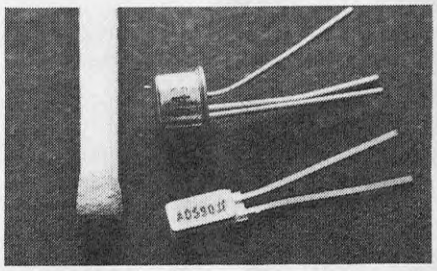
To ensure the appropriate accuracy, high stability 1% metal film resistors and cermet trimpots are used. Capacitor C1 provides compensation for the op-amp, to ensure stability.

The AD590 is available in a number of accuracy grades. The 'M grade' device will give better than ±0.05° accuracy from 0° to 100° Celsius. It costs around $60, however. For about $5, you can purchase the 'J grade' AD590 which will give an accuracy of ±0.3° from 0° to 100°C. The accuracy you get depends on a number of factors (discussed later) and the type of circuit.

The simplest circuit you could use is shown in Figure 1. This will give temperature directly in the Kelvin scale with a voltage/temperature relationship of 1 mV/°K. Thus at a typical ambient temperature of +25°C (298°K), the output will be 0.298 V. The output can be 'trimmed' to the correct temperature (calibrated) at one temperature point by the 200 ohm cermet trimpot. This is a 'one trim' circuit. With the AD590J, accuracy will be ±2° over the range from 0° to 100°C.

A circuit which provides for two trim, or calibration, points results in much better accuracy, Also, a more convenient voltage/temperature relationship is useful, which requires the output of the sensor to be scaled. An op-amp can be used for this to provide a stable gain. A figure of 10 mV/°C (or /°K) is suitable, and that's what I chose.

The accompanying photograph shows the two package styles compared to a match head. The TO-52 can (H package) is for general use. It has a longer time constant — the time taken to stabilise after changing the package's temperature — than the ceramic flat pack (F package). Typically, the H package will take four minutes to stabilise in still air, but the F package will only take about half that time. When applied to an aluminium block (e.g: a heatsink), the H package will typically take four seconds to stabilise, while the F package will take around half a second.



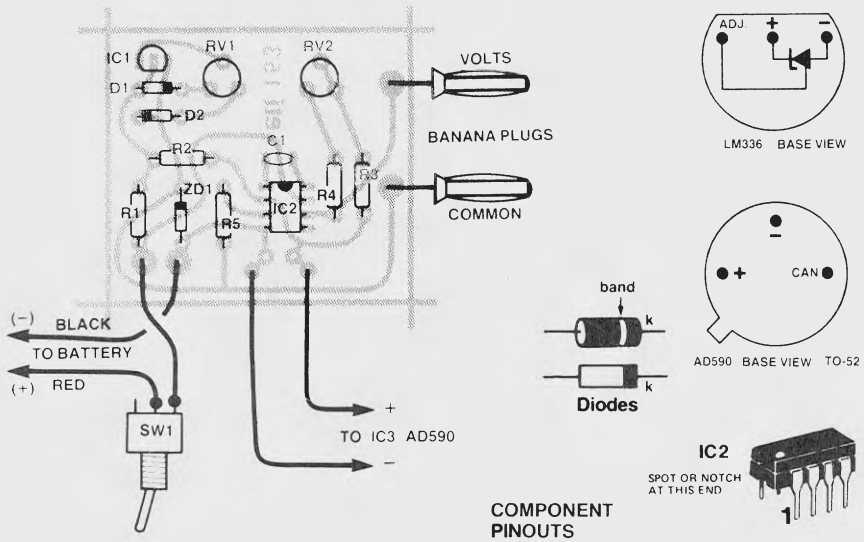
Tiny, what? The two versions of the AD590 packaging, compared to a match head. Above is the H package (TO-52); below is the ceramic F package.

Construction

The project was designed to fit inside a small jiffy box with a metal lid having overall dimensions of 30 x 50 x 80 mm. They're common and low in cost.

All the electronics, except the AD590 sensor, are mounted on a small pc board. This can be assembled first. Just check your pc board before assembling the components, ensuring there are no broken tracks or shorts between tracks and that all holes are correctly drilled.

The components can be assembled to the pc board in any order, just watch that you put the two ICs, the two diodes and the zener the right way round. Don't take too long to solder the resistors as they are high stability types, but ensure that each joint is properly made. ▶



PARTS LIST — ETI 153

Resistors ..... all 1% metal film, unless noted
- R1 ..... 1k5
- R2, R3 ..... 9k1
- R4 ..... 680R
- R5 ..... 4k7
- RV1 ..... 10k cermet, horizontal pc mount trimpot
- RV2 ..... 500R cermet, horizontal pc mount trimpot

Capacitor
- C1 ..... 33p ceramic

Semiconductors
- IC1 ..... LM336 precision voltage reference
- IC2 ..... uA301, LM301 gen. purp. op-amp
- IC3 ..... AD590J precision temp. sensor (see text)
- D1, D2 ..... 1N914 or 1N4148
- ZD1 ..... 5V1, 400 mW zener (see note).

Miscellaneous
ETI-153 pc board; UB5 zippy box (28 x 54 x 83 mm); two banana plugs; hookup wire, cable, probe etc.

NOTE: A 5V6/1 W zener may be used but, if so, change R1 to 1k.

Price estimate $18 — $20

I mounted the banana plugs in the box between the plastic pillars at one end so that the whole unit plugged straight into a normal multimeter. To do this, the plugs must be spaced ¾" (19 mm) which is known as 'GR' spacing. To make this easier, I have laid out the pc board with the output pads spaced exactly at 'GR' spacing. The board can be used as a template when drilling the holes for the banana plugs.

Remove the plastic body of each plug and solder about 10 cm of insulated hook-up wire to each. Using the pc board, drill pilot holes of about 1 mm diameter through the box near one end and enlarge them until the banana plugs will fit through the box.

Cut the plastic body of each plug in half and install the plugs, tightening the body from the inside for each plug.

Drill a hole for the switch, between the plugs, in the end of the box making sure that the switch will not foul the plugs.

If the switch you have will not mount as mine did then you may fit it into the lid of the box, but keep it near the end where the plugs are.

Also drill a hole, in the end of the box opposite the switch, for the cable from the sensor.

Wire up the battery connector, switch and plugs, following the overlay. Don't connect the AD590 yet. Plug the unit into your multimeter, set RV2 to the mid-position and set you multimeter to the 20 V range. Switch on and adjust RV1 to obtain a reading of –2.73 V.

The probe

I made the probe from the barrel of a BIC 'finepoint' pen. Discard the innards and cut back the pointed end by about 2 mm. Use a 7/32" drill bit to carefully enlarge the hole at the pointed end to a depth of 2 mm.

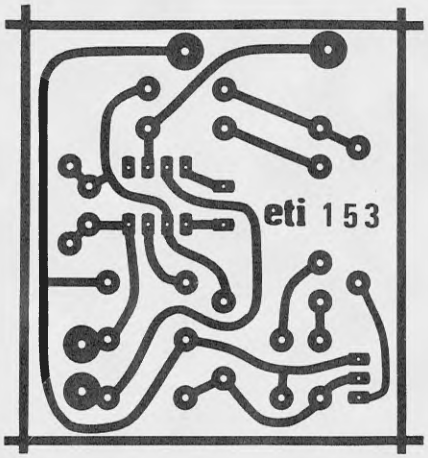
Cut the –ve lead of the AD590 back about 6-7 mm. This identifies the two leads. Now snip the tab off the AD590 and file the tab stump back to allow the device to slip into the pointed end of the modified pen barrel.

The lead between the sensor and the electronics is a convenient length of small figure-8 flex with one marked lead (i.e: 'light speaker wire'). I used a length about one metre long. Slip one end through the pen barrel and trim back the unmarked lead by about 6 mm. Solder the marked lead to the AD590 +ve lead, the unmarked (cut back) lead to the AD590 –ve lead.

It is important to keep moisture away from any exposed conductors, since only one microamp of leakage will cause a one degree error. Consequently, after soldering I coated all exposed conductors and the base of the AD590 with two coats of nail polish*, allowing drying time between coats.

Now seal the AD590 into the end of the pen barrel. I used a silicone sealant ('Silastic'), poking some down the pen barrel, in the pointed end first, then putting a blob on the base of the AD590 before pushing it in place. Wipe away any excess. Put a blob down the other end of the barrel, too.

Take the free end of the cable, strip and tin the two wires. Pass this end through the hole you drilled in the box for it and knot the cable on the inside leaving about 60 mm to the end. Solder the two wires to the pc board as per the overlay. Remember, the marked lead is from the +ve of the AD590.



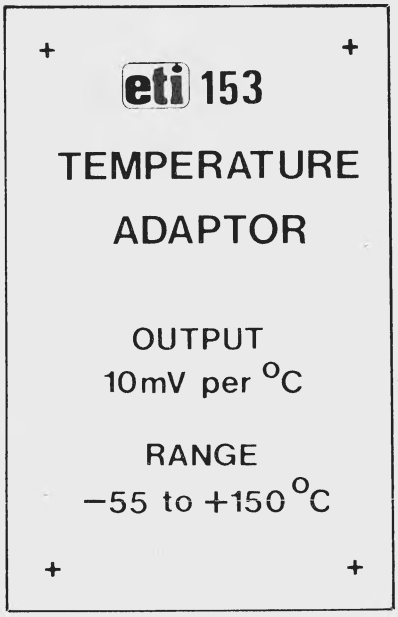
Artwork. Full size artwork for the pc board and front panel. You can obtain a 1:1 negative or positive, for making your own pc board and/or Scotchcal, for $1.00 each, post paid, ($2.00 the pair) from **ETI-153 Artwork, ETI Magazine, P.O. Box 21, Waterloo NSW 2017.** Make your cheque or money order out to ETI Artwork Sales'. Ensure you ask for a **positive** or **negative,** as you require.

Switch the unit on and set the multimeter to the 2 Vdc range (unless it's an auto-ranging meter). You should get a reading of around 0.200-0.250 or so, depending on the ambient temperature. If not, reverse the leads from the AD590 and try again. If you still get no result, there's a fault which you'll have to track down and correct.

If all's well, you can now calibrate the unit for maximum accuracy.

Calibration

There are three main methods of calibration; I shall describe them in order of increasing



accuracy.

The simplest way is to leave RV2 set in the mid-position and adjust RV1 to read a known temperature. This requires a thermometer to be placed in the same thermal environment as the AD590 sensor. This method will result in accurate readings over a range of 10 to 20 degrees, depending on the resolution of the reference thermometer.

The second calibration technique involves adjusting RV1 to obtain a reading at 0°C with the sensor immersed in melting ice, then placing the sensor in steam and adjusting RV2 for a reading at 100°C.

For this method, a good ice bath is a tall glass (but a vacuum 'Thermos' flask is better) filled with pure crushed ice which is then allowed to melt until the liquid level about two-thirds fills the glass.

Place the sensor about 20 mm below the water surface, wait for the multimeter reading to stabilise, then adjust RV1 to obtain a reading of 0.000 V.

Next, surreptitiously borrow a small saucepan from the kitchen and half an hour of kitchen time. Boil up a litre or two of water so that it's boiling rapidly with plenty of steam emitting. Place the sensor in the steam cloud, allow a few seconds for the reading to stabilise, then adjust RV2 for a reading of 1.000 V. Note that the boiling point of water depends on altitude so this method is strictly only accurate at or near sea level, unless you can borrow a reference thermometer of sufficient accuracy.

The most accurate calibration is obtained by using a laboratory grade thermometer and immersing it and the AD590 in a stirred liquid bath — first one bath at a temperature low in the desired range, then in another at a temperature high in the range. For best accuracy, you need to repeat the procedure several times, adjusting RV1 at the lower temperature and RV2 at the higher temperature, until the desired accuracy is reached.

With the calibration completed, you can complete the assembly. Cut a rectangle of thin cardboard the same size as the box lid, then cut off the corners. The pc board goes in the box with the components facing down, the battery going in first. The cardboard goes between the copper side of the pc board and the lid, preventing shorts.

I dressed up the box lid with a Scotchcal label. If you want to do the same, apply the Scotchcal to the lid before screwing it to the box. Peel off the backing at one end and carefully align it against the edge of the panel. Smooth it down and then continue peeling off the backing, smoothing the label in place as you go. Any air bubbles can be removed by rubbing them towards the nearest edge.

That's it!

For improved thermal coupling under some circumstance, a small heatsink can be slipped over the AD590. I used a Thermalloy No. 2224B. Note that this slows down the thermal response. When measuring the temperature of solid objects, particular metal objects (transistor cases, heatsinks, resistor bodies, etc), use a little thermal paste to improve thermal coupling. ●

ACCURACY

The overall accuracy of the ETI-153 is determined by three main factors: (i) *calibration error and overall accuracy* of the AD590 sensor; (ii) the *thermal environment* in which it is used, and (iii) *drift in the electronics* due to changes in the ambient temperature.

1. Calibration error and non-linearity of the AD590. This factor is easily calculated by referring to the table from the Analogue Devices applications note (Table 1), reproduced here. The 'Number of Trims' column refers to the type of circuit used with the AD590J. For the ETI-153, use the 'Two Trims' data. For the simple Kelvin circuit (Figure 1) use the 'One Trim' data.

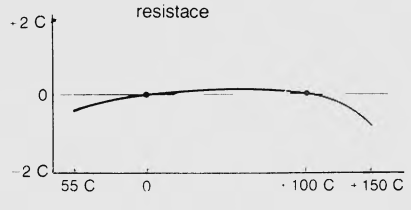
To obtain the error after calibrating at 0°C and 100°C, look down the row where the temperature span is 100°C until you find the column under 0°C, which is the lowest temperature in the span. The error is found to be ±0.3°C. If you calibrate the instrument at 0°C and 50°C, the error is ±0.1°C. These figures exclude any trim errors due to the calibration technique, of course.

2. Thermal environment. The AD590 dissipates a tiny amount of power owing to the voltage across it and the current flowing through it. This power causes self-heating of the sensor and must be allowed for so as to obtain maximum accuracy.

The rise in sensor temperature due to self-heating is given by:

$$T_J - T_A = P\,(\theta_{JC} + \theta_{CA}).$$

Where T_J is the junction temperature of the AD590.
T_A is the ambient temperature
p is the power dissipated
θ_{JC} is the chip-to-case thermal resistance
θ_{CA} is the case-to-medium thermal resistace



Typical two-trim accuracy.

J GRADE Number Of Trims	Temperature Span (°C)	Lowest Temperature In Span (°C) -55	-25	0	+25	+50	+75	+100	+125
None	10	4.2	4.6	5.0	5.4	5.8	6.2	6.6	7.2
None	25	5.0	5.2	5.5	5.9	6.0	6.9	7.5	8.0
None	50	6.5	6.5	6.4	6.9	7.3	8.2	9.0	–
None	100	7.7	8.0	8.3	8.7	9.4	–	–	–
None	150	9.2	9.5	9.6	–	–	–	–	–
None	205	10.0	–	–	–	–	–	–	–
One	10	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.3
One	25	0.9	0.6	0.5	0.5	0.5	0.6	0.8	0.9
One	50	1.9	1.5	1.0	1.0	1.0	1.5	1.9	–
One	100	2.3	2.2	2.0	2.0	2.3	–	–	–
One	150	2.5	2.4	2.5	–	–	–	–	–
One	205	3.0	–	–	–	–	–	–	–
Two	10	0.1	*	*	*	*	*	*	0.1
Two	25	0.2	0.1	*	*	*	*	0.1	0.2
Two	50	0.4	0.2	0.1	*	*	0.1	0.2	*
Two	100	0.7	0.5	0.3	0.7	1.0	–	–	–
Two	150	1.0	0.7	1.2	–	–	–	–	–
Two	205	1.5	–	–	–	–	–	–	–

*Below 0.05° C

Table 1.

Typical values of $\theta_{JC} + \theta_{CA}$ are given in Table 2.

Using this information, the temperature rise at 25°C (= 298°K) due to a power dissipation of approximately 298 uA by 4.5 V = 1.3 mW (in still air, without a heatsink), is given by:

$$T_J - T_A = 1.3 \times 10^{-3} \times 480 = 0.62°C.$$

Note however, that $T_J - T_A$ is directly proportional to the absolute temperature and hence, if the ETI-153 is calibrated with the AD590 in the same medium as it will be used, then the adjustment of the scale factor, with RV2, will compensate for the self-heating effect. In any case, the error is reduced by better thermal coupling to the medium.

The other main environmental effect is the thermal time constant, or the speed of response of the sensor to temperature changes. The column, τ, in Table 2 gives the time required to reach 63.2% of a step temperature change. The response is given by:

$$T(t) = T_{initial} + (T_{final} - T_{initial})\,(1 - e^{-t/\tau})$$

3. Drift in the electronics due to ambient temperature changes. There are three error terms here. *Thermocouple errors* are introduced by dissimilar metal junctions being at different temperatures. This can only be seen in the AD590 end of the circuit, since all the electronics in the jiffy box can be assumed to be at the same temperature.

Since the AD590 has a power supply rejection of 0.5 uA/V and the maximum possible thermocouple voltage is far less than 20 mV, the effect on the output is negligible.

The electronics in the jiffy box operates at *ambient temperature* which introduces errors when it varies from what it was during calibration of the instrument.

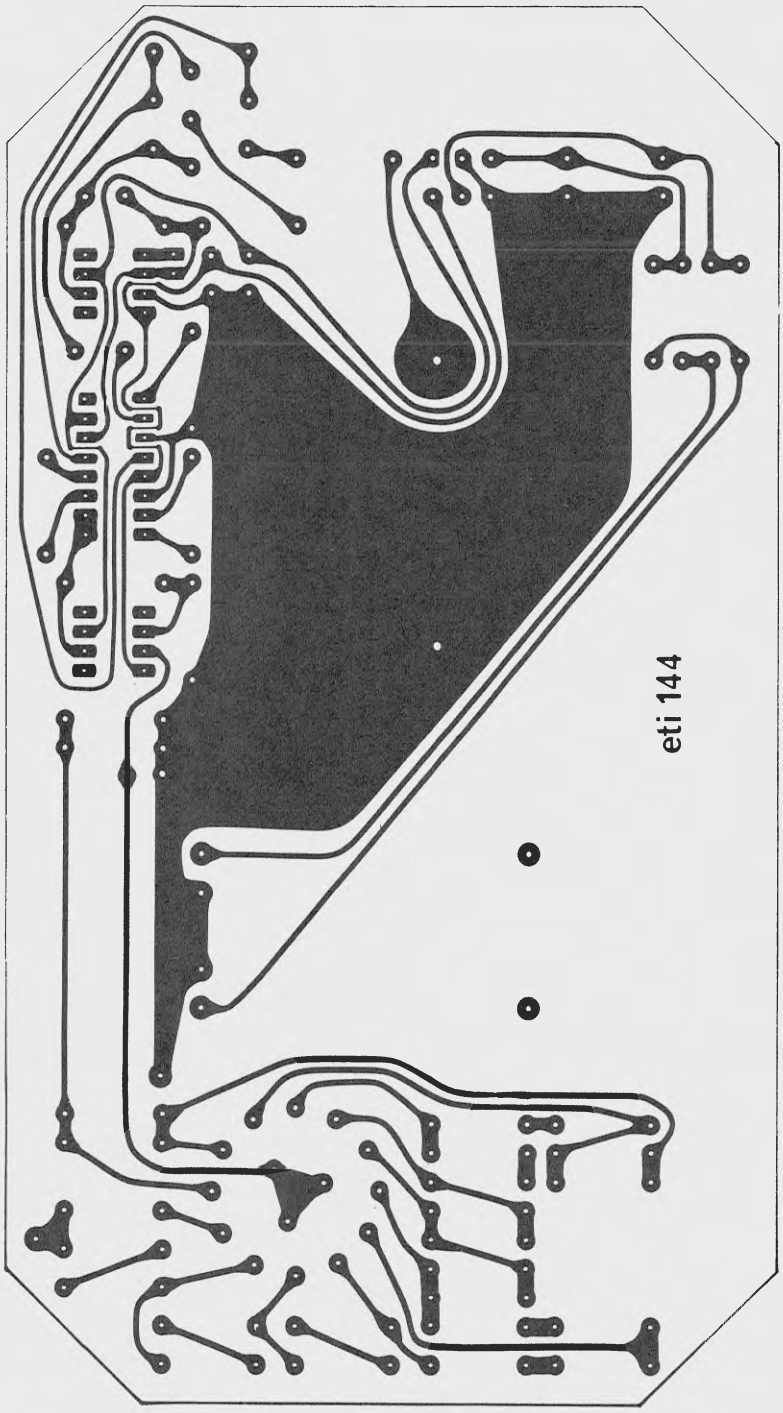
The major contribution to this error comes from the two ICs. Using the worst-case figures for temperature changes over a 0° — 70 C ambient range results in a maximum error of less than 1 C in the output. In practise, the drift from this cause should be much less.

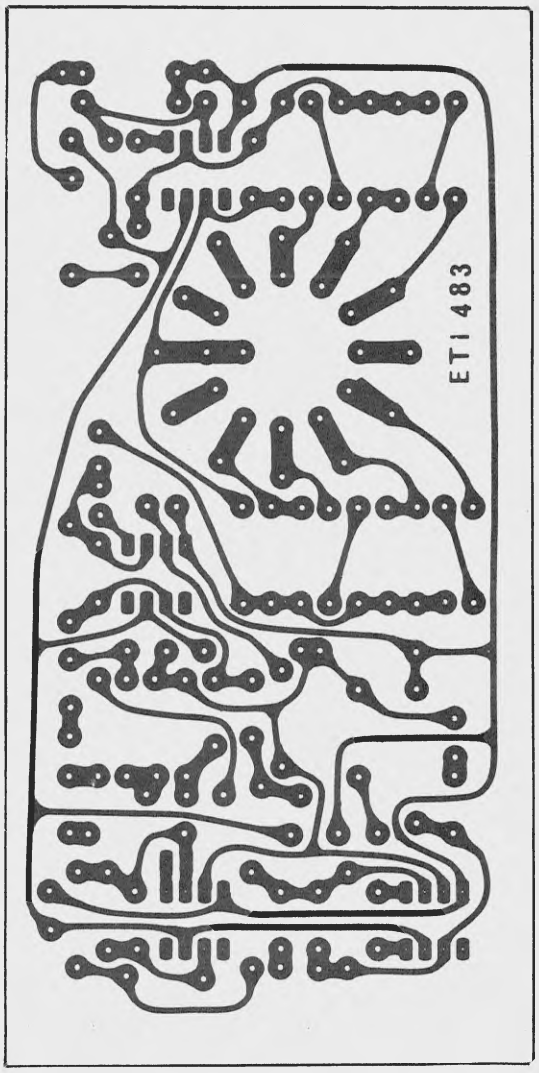
I subjected the prototype to a blast from a hair dryer for about one minute which resulted in a temperature change of 0.1 C. Few multimeters would have better stability than the ETI-153 under these conditions.

Over normal ambient temperature changes ranging from about +15 to +35 , the output change caused by drift in the electronics should not degrade the accuracy of the AD590.

MEDIUM	$\theta_{JC} + \theta_{CA}$ (C/watt) H	F	τ (sec) H	F
Aluminium block	30	10	0.6	0.1
Stirred oil	42	60	1.4	0.6
Moving air				
with heatsink	45	—	5.0	—
without heatsink	115	190	13.5	10.0
Still air				
with heatsink	191	—	108	—
without heatsink	480	650	60	30

Table 2


eti 144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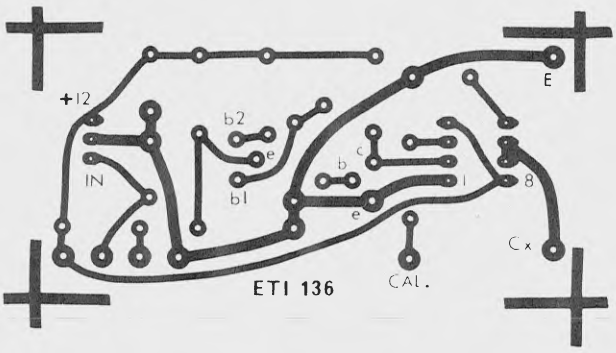
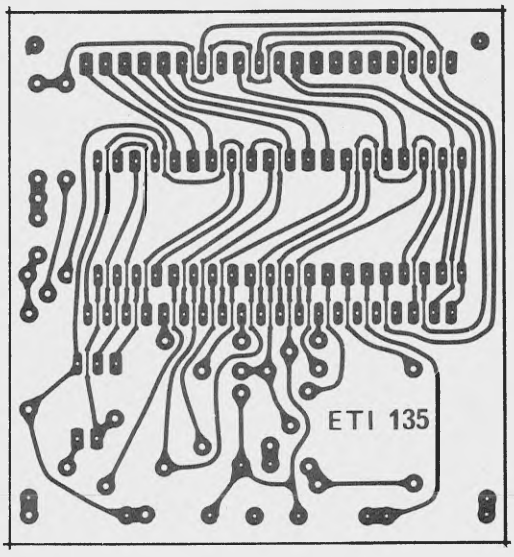

+12
IN
b2
b1
e
b
c
e
1
8
E
Cx
CAL.
ETI 136

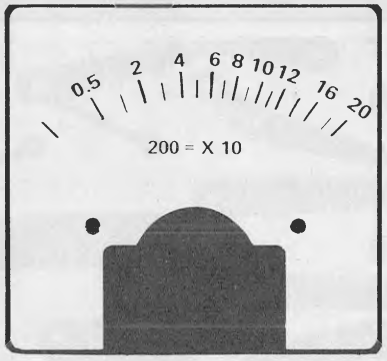

ETI 135

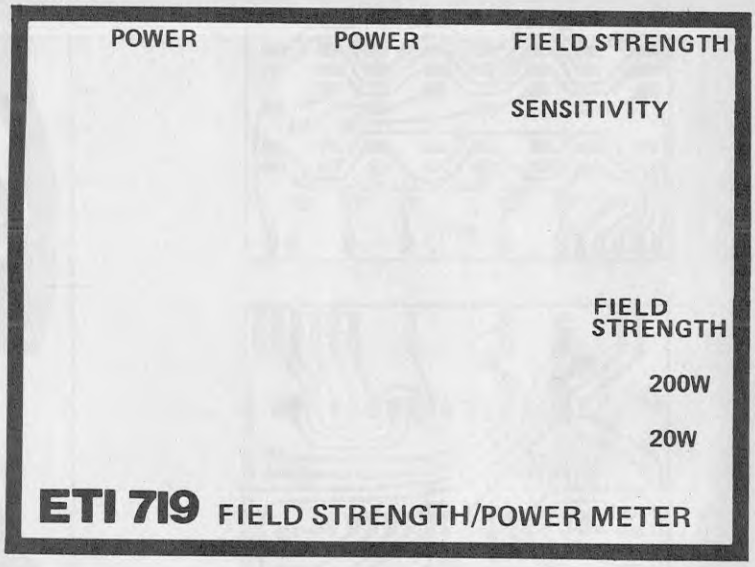
eti
591B

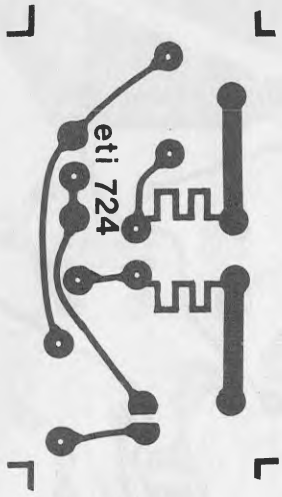
eti 591A

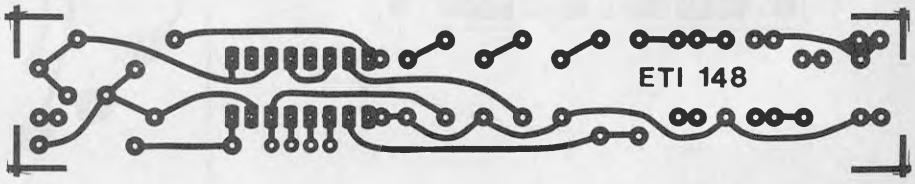
eti 717

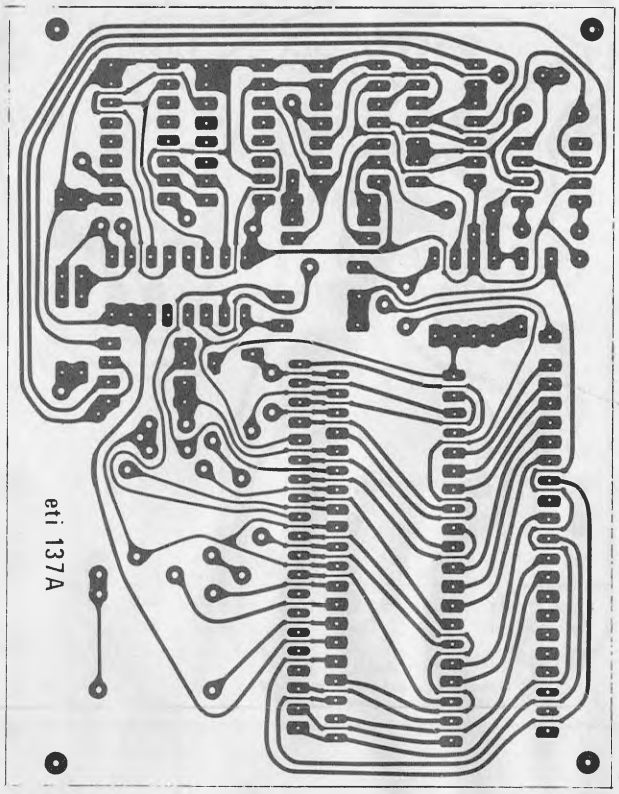
eti 138

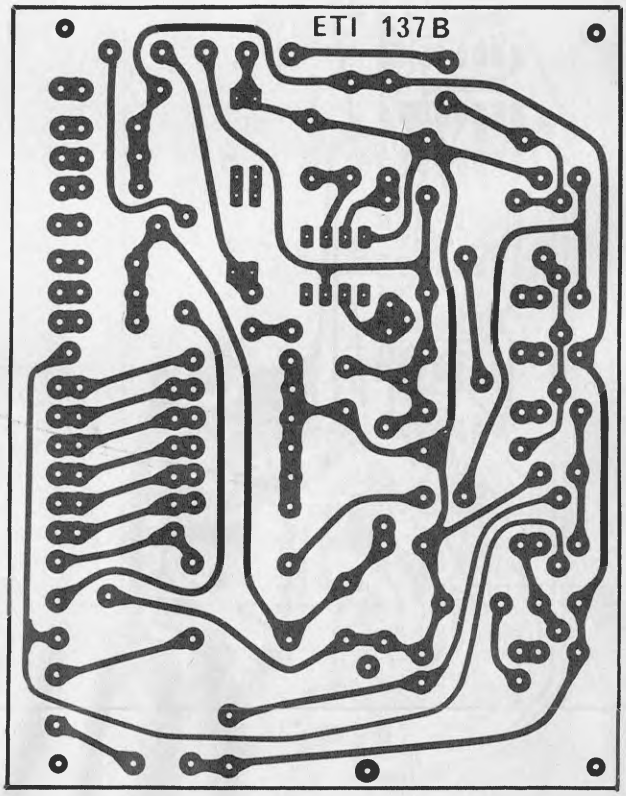

0.5
2
4
6
8
10
12
16
20
200 = X 10

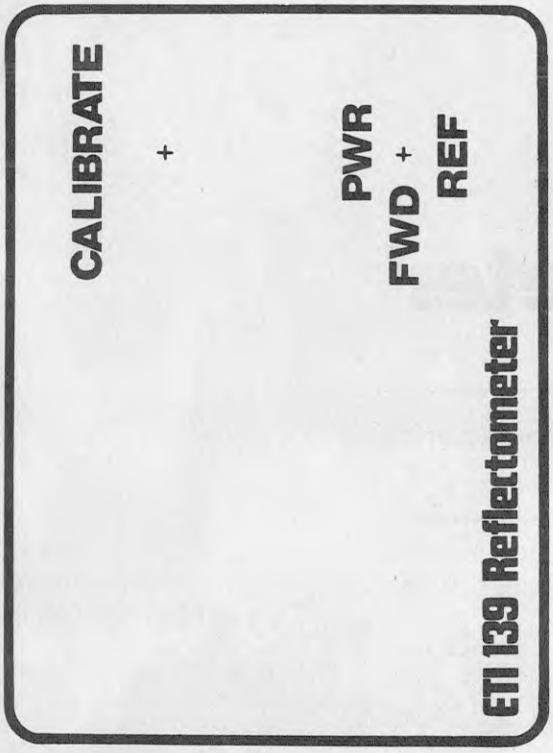

POWER
POWER
FIELD STRENGTH
SENSITIVITY
FIELD STRENGTH
200W
20W
ETI 719 FIELD STRENGTH/POWER METER

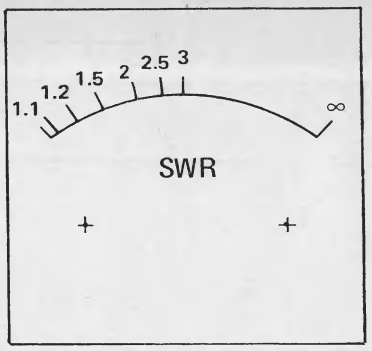

eti 724

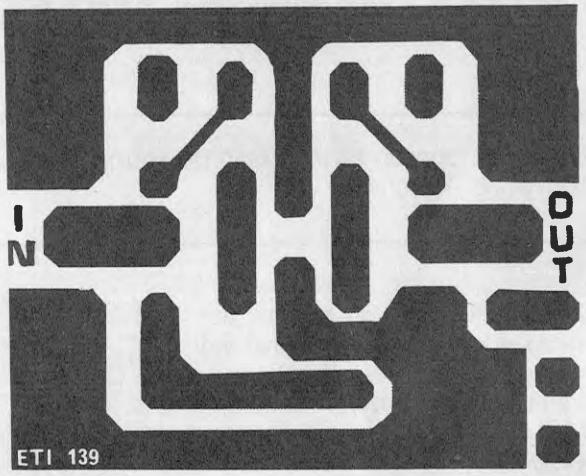

ETI 148


eti 137A


ETI 137B







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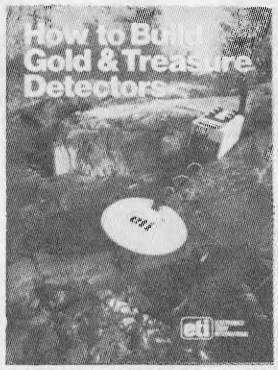

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True RMS voltmeter

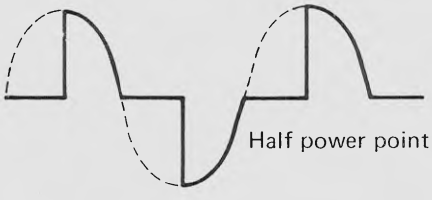
The use of a special IC results in performance greatly improved over conventional designs.

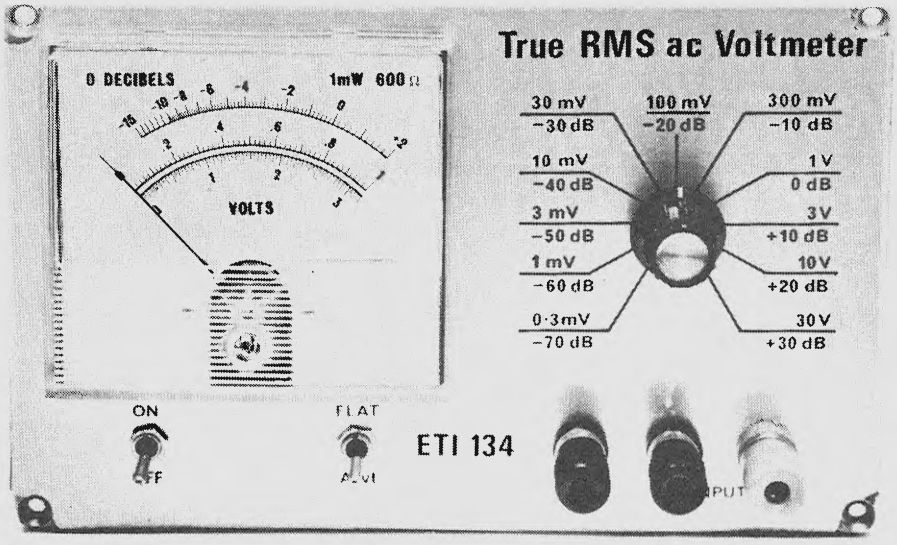
MOST METERS which can measure ac signals do so by rectifying the signal and then measuring the average voltage. With a sinewave the average voltage is 0.637 of the peak voltage while the rms value is 0.707 of the peak. Therefore a correction factor of 1.11 is built into the meter to give the rms value of the signal.

Provided you stick with sinewave signals these meters are adequate. With any other waveform, however, they are not accurate. With a square wave the error is 11% and with pulse wave forms the error increases.

Before continuing we should explain what rms means and its significance. Without getting mathematical, the rms value of any wave form is the same as a dc value which would produce the same heating effect in a resistor. For example:

Power in a load can be varied by using phase control (i.e., light dimmer) where the time the load is connected to the mains is variable. The rms value is difficult to calculate except at the point where it is half on—half off. The power then is obviously half power.





If the input voltage is 240 V and the load is 240 ohms the power (maximum) is given by

$$P = \frac{E^2}{R} \text{ or } \frac{240 \times 240}{240} = 240 \text{ W}$$

Half power therefore is 120 W. The voltage corresponding to this is given by

$$E = \sqrt{P \times R} \text{ or } 170 \text{ V (rms)}$$

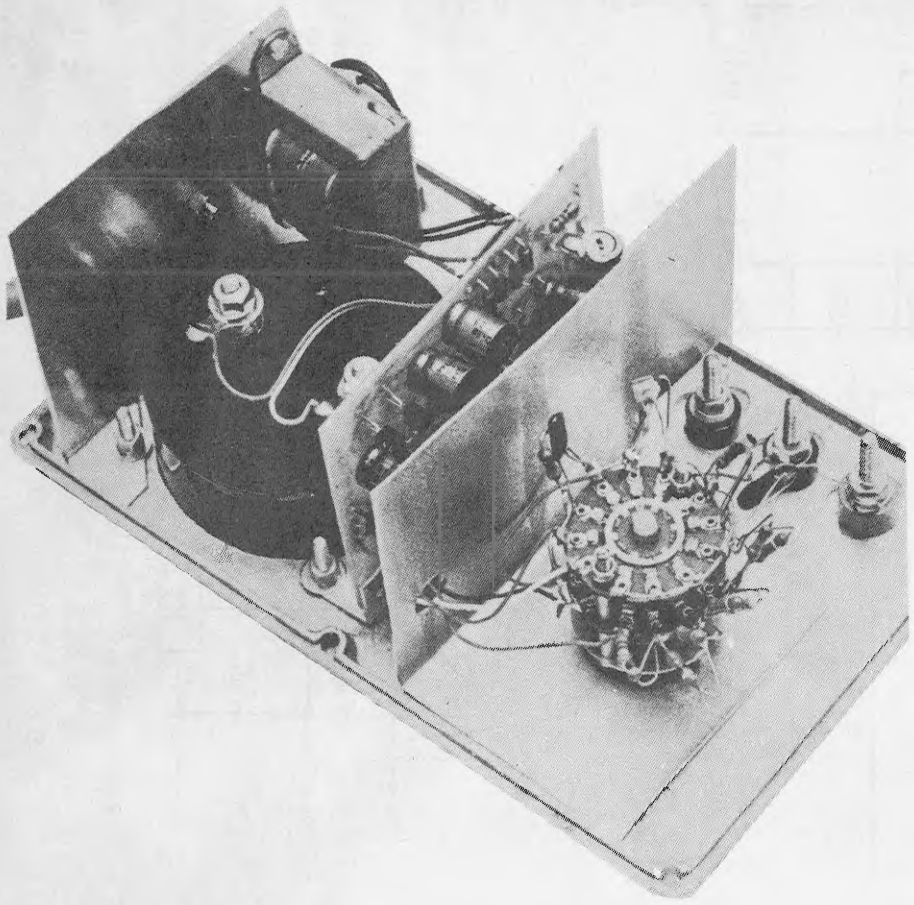
On a "normal" meter this will read 120 V or an error of 30%.

This design uses an rms detector IC, which is basically a small, special-purpose analogue computer to mathematically calculate the true rms value for any waveform.

Design Features

The design of the voltmeter is basically simple, starting with an attenuator in the front end, then an amplifier with a high input impedance and switchable gain which, with the attenuator, gives the range selection. A filter is then added to give the "A" weighting and the rms detector IC (LH0091) does the rest.

The output of the input amplifier is 60 mV, independent of range selected, for an input corresponding to the full scale reading. This gives a maximum gain of 46 dB on the 0.3 mV range. There is a loss of about 2.3 dB in the filter (at 1 kHz) and the spare amplifier in IC2 is used to provide a gain of 20 dB giving 500 mV (for full scale reading) before the rms detection is done. The



SPECIFICATION – ETI 134

Meter Type	rms reading ac only
Ranges	0.3, 1, 3, 10, 30, 100, 300 mV 1, 3, 10, 30 V
Accuracy	±3% nominal (crest factors up to 3) – 8% at crest factor of 10
Input Impedance	1 megohm in parallel with 25 pF
Weighting Networks	Flat or 'A' weight
Frequency Response	10 Hz – 20 kHz

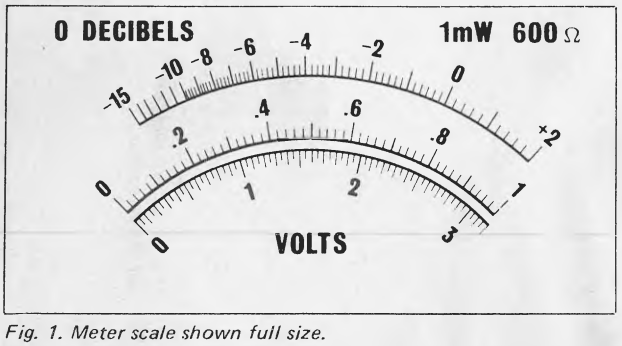


Fig. 1. Meter scale shown full size.

rms detector section has unity gain with 500 mV rms in giving 500 mV dc out.

However things are never that simple. With a total of 60-odd dB gain, along with the requirement for a 1 M input impedance, we have an excellent formula for an oscillator. With the third try (yes, we have failures too) with adequate shielding and layout, stability was obtained and this final design is presented here.

The spare IC in the LH0091 is normally used to buffer, filter or amplify the output of the rms converter but we used it before so as to buffer the filter network and save an additional op amp (the input of the rms converter is only 5 k ohms). The output voltage from the converter is only 500 mV but this is adequate to drive a meter. We could have provided more gain in the buffer stage so giving a higher output but this would lead to greater errors with high crest factor waveforms.

We have limited this instrument to ac signals as this eliminates the need for balance controls to correct for drift when measuring low level signals. This normally is of no consequence as most signals, i.e., output of a tape recorder, sound level meter, etc., have no dc component. If dc capability is needed, capacitors C1, 8, 9, 14, 15 and 16 have to be shorted out, a zero adjustment potentiometer added to IC1 along with the potentiometers needed to offset adjust IC2.

Construction

If the printed circuit board is used along with the layout and shields as described there should be no problems with construction. The wires associated with the rotary switch should be no longer than necessary to minimise any pickup. The box should be earthed to the mains earth and the front panel earth terminal (left hand one) should also be connected to earth.

Use

When measuring low level signals there may be 50 Hz pickup unless the common side of the input signal is connected to ground. This may be done either in the unit under test or on the meter (hence the earth terminal). Also with the meter terminals open circuited the meter will give some reading. However, as the output impedance of low level signals (0.3 mV and less) is normally relatively low this is normally no problem.

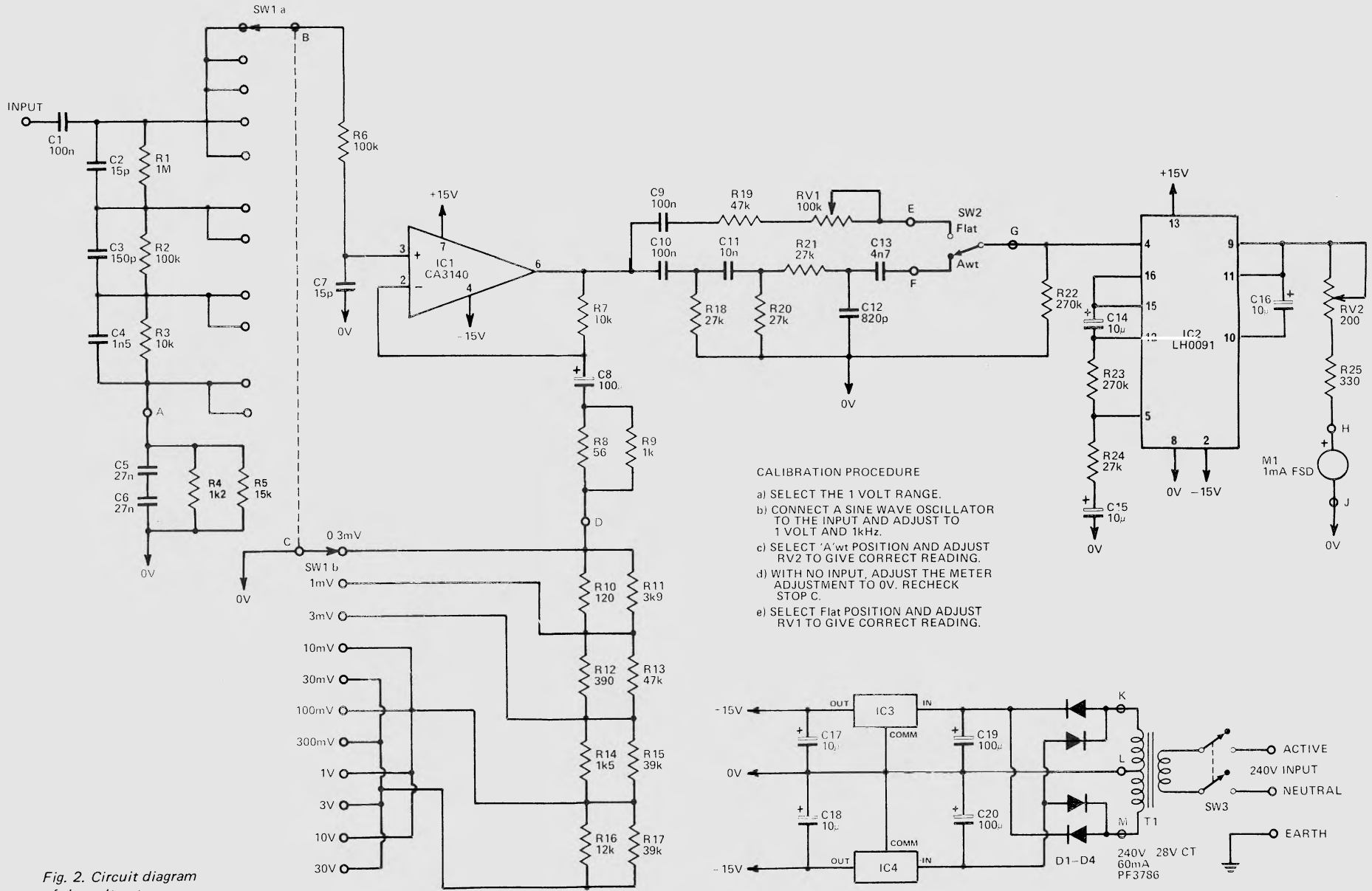


Fig. 2. Circuit diagram of the voltmeter.

HOW IT WORKS – ETI 134

The input signal is attenuated by the network R1–R5 and C2–C6; the appropriate attenuation is selected by SW1a. This gives 0 dB, 20 dB, 40 dB and 60 dB. The output of SW1a is buffered by IC1 which is a FET input op-amp. This amplifier has a gain which is switchable giving 5.56 dB, 15.56 dB, 25.56 dB, 35.56 dB and 45.56 dB. By selecting a combination of these two variables the eleven ranges from 0.3 mV to 30 V are obtained. The output of IC1 for full scale reading is 60 mV.

The output of IC1 goes to the 'A' wt filter network and also directly (via R19 and RV1) to SW2. This selects either 'A' weighting or flat response. As the filter has 2.3 dB loss at 1 kHz the "flat" position is also attenuated (hence R19, RV1) to maintain calibration.

The rms detector IC provides a gain of 20 dB before the detector; the output of the detector is about 500 mV for full scale reading.

The power supply is simply a full wave rectified supply giving both plus and minus voltages of about 20 V, which are then regulated to ±15 V by IC3 and IC4.

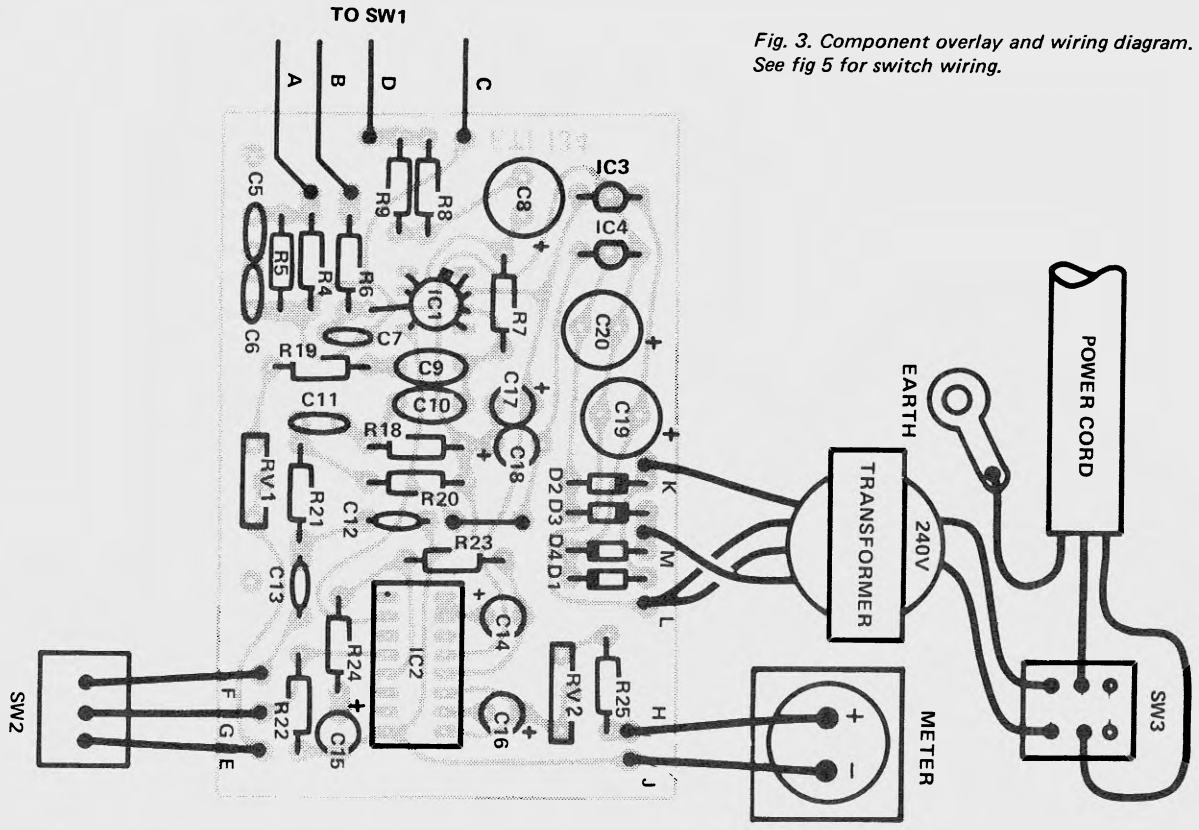


Fig. 3. Component overlay and wiring diagram. See fig 5 for switch wiring.

PARTS LIST - ETI 134

Resistors

All ½ W 5%, except where marked.

R1	1M	1%
R2	100k	1%
R3	10k	1%
R4	1k2	1%
R5	15k	
R6	100k	
R7	10k	1%
R8	56	1%
R9	1k	
R10	120	1%
R11	3k9	
R12	390	1%
R13	47k	
R14	1k5	1%
R15	39k	
R16	12k	1%
R17	39k	2%
R18	27k	
R19	47k	
R20,21	27k	
R22,23	270k	
R24	27k	
R25	330	

Potentiometers

RV1	100k	trim
RV2	200 ohm	trim

Capacitors

C1	100n	polyester
C2*	15p	ceramic
C3*	150p	"
C4*	1n5	polyester
C5, 6*	27n	"
C7	15p	ceramic
C8	100µ	25V electro
C9, 10	100n	polyester
C11	10n	"
C12	820p	ceramic
C13	4n7	polyester
C14-C18	10µ	25V electro
C19, 20	100µ	25V electro

* These capacitors should be as accurate as possible as they affect accuracy above 10kHz.

Semiconductors

IC1	CA3140	op amp
IC2	LH0091	RMS converter
IC3	78L15	regulator
IC4	79L15	regulator
D1-D4	1N4001 or similar	

Miscellaneous

PC board	ETI 134
SW1	2 pole 11 position OAK switch
SW2	SPDT minature toggle switch
SW3	DPDT minature toggle switch
T1	Transformer PF3786 (28V ct)
M1	Meter 1mA scaled as shown

3 terminals (red, black green)
Box Eddystone 6357P
Metal brackets and shields (see Fig 7)
3 core flex and plug
Scotchcal or aluminium front panel
16 pin socket for IC2
Knob

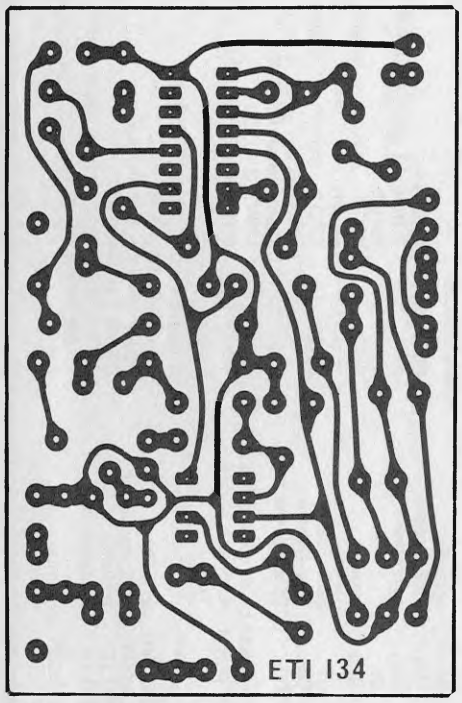


Fig. 4. Printed circuit layout.
Full size 90 x 60 mm.

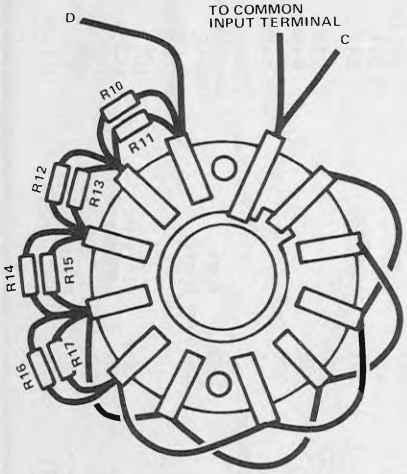
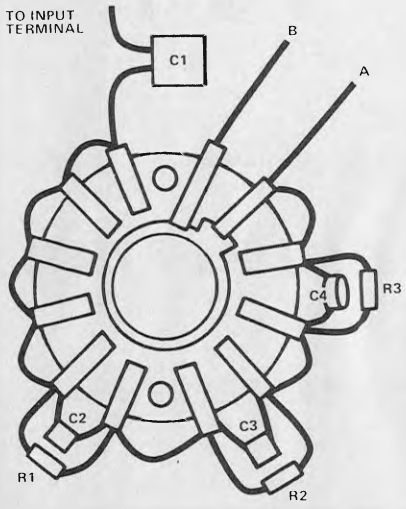


Fig. 5. Connection of the range switch drawn in the 30 V position.



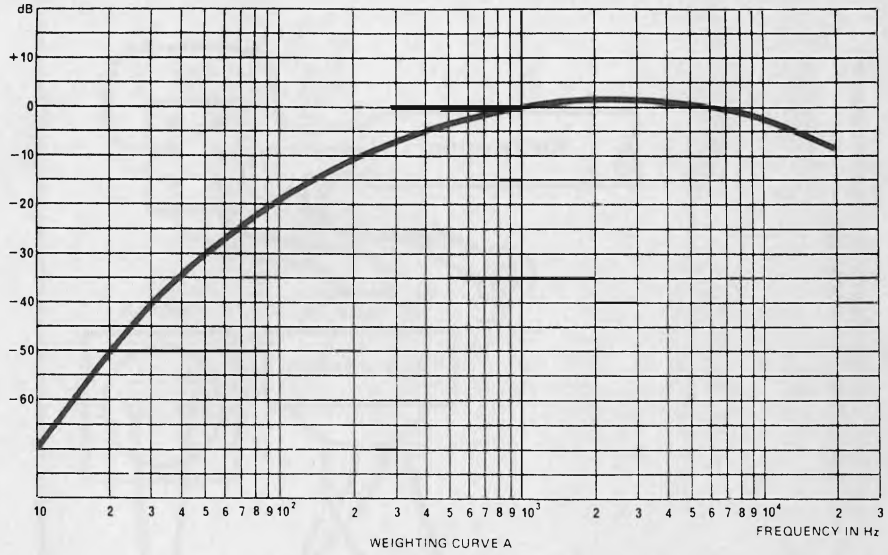


Fig. 6. The response in the " A " weight position.

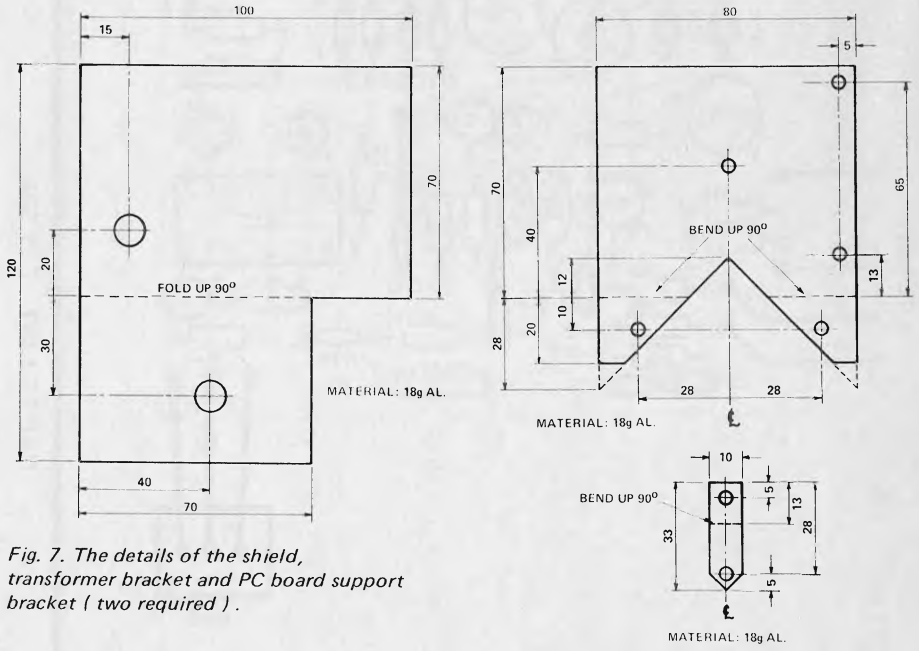
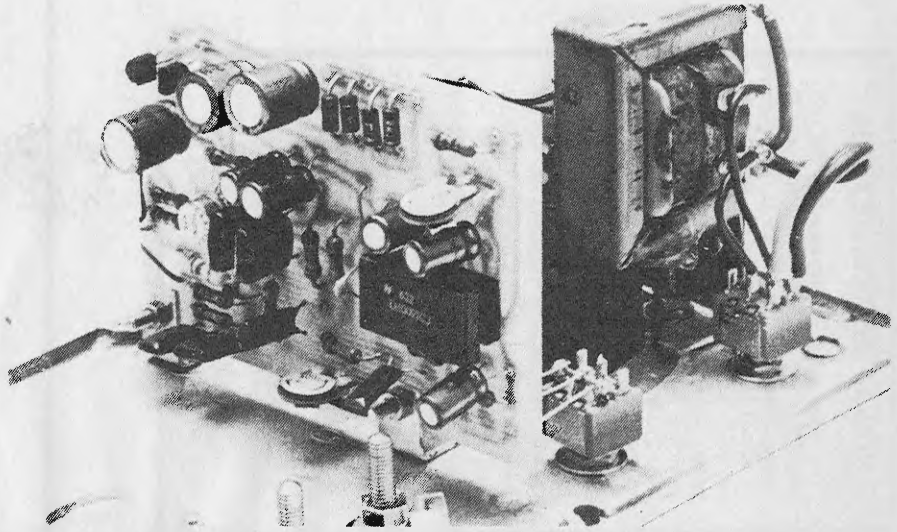


Fig. 7. The details of the shield, transformer bracket and PC board support bracket (two required) .



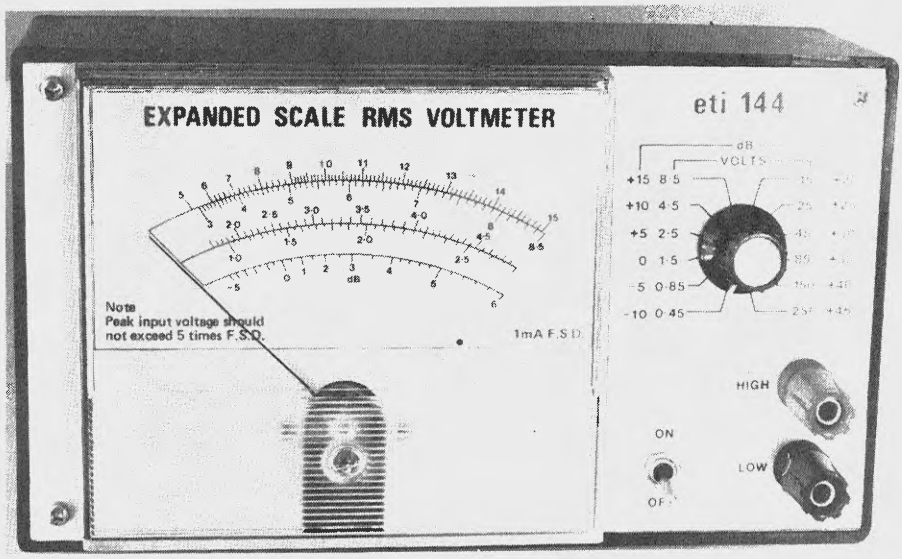
Expanded scale RMS voltmeter

Inexpensive RMS voltmeter measures 150 mV to 270 V in twelve expanded scale ranges, and has two per cent accuracy.

THE RMS VOLTMETER described in the previous article is an ac only instrument which uses an LH0091 RMS converter IC.

The instrument described in this article, while perhaps not as versatile in some ways as the ETI 134 which has a 0.3 mV to 30 V range and an A-weighting filter, is simpler to construct, will measure dc signals (square waves and pulses etc referenced to zero volts) and is less expensive.

This instrument will measure 150 mV to 270 V in 12 ranges and features a large (90 mm scale) meter, 2% accuracy and an expanded scale for ease of reading.



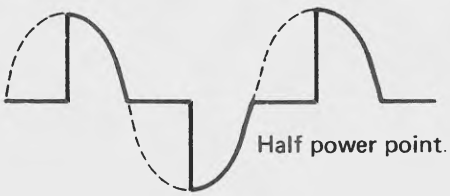


Fig. 1. The output waveform of a light dimmer running at half power.

What is RMS?

At this stage, it would be a good idea to recap just what RMS means and its significance. Simply, the RMS value of any waveform is equal to that dc value which would produce the same heating effect in a resistor.

As an example, let's take the case of a light dimmer. The power in the light (the load) is varied using phase control in an SCR circuit. This varies the amount of time the load is connected to the mains over part of each mains cycle (see Fig. 1). The RMS value of the waveform across the load in this case is difficult to calculate, except at the point where it is half-on and half-off. The power is then obviously half the maximum value.

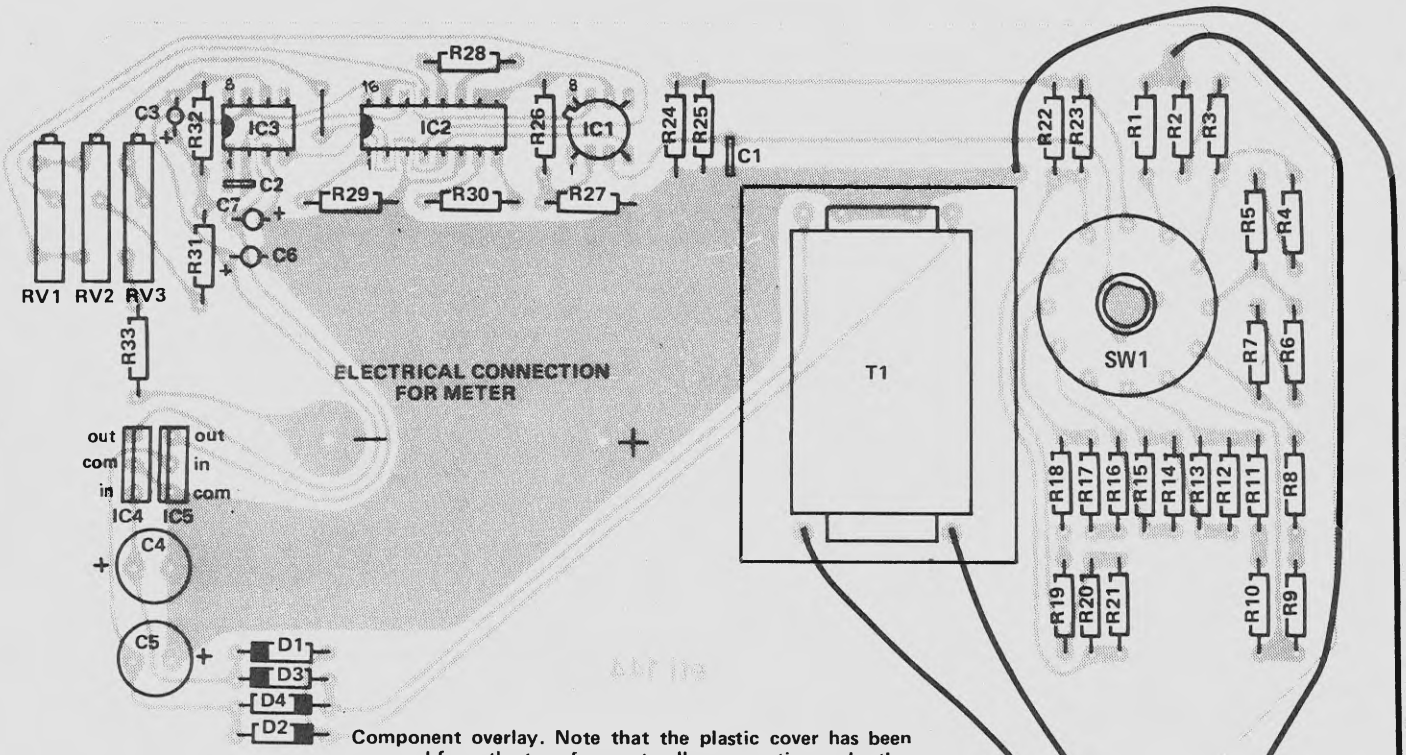
If the input voltage is 240 V and the load is 240 ohms, the power at maximum can be calculated from:—

$$P = \frac{E^2}{R} \text{ or } \frac{240 \times 240}{240} = 240 \text{ W}$$

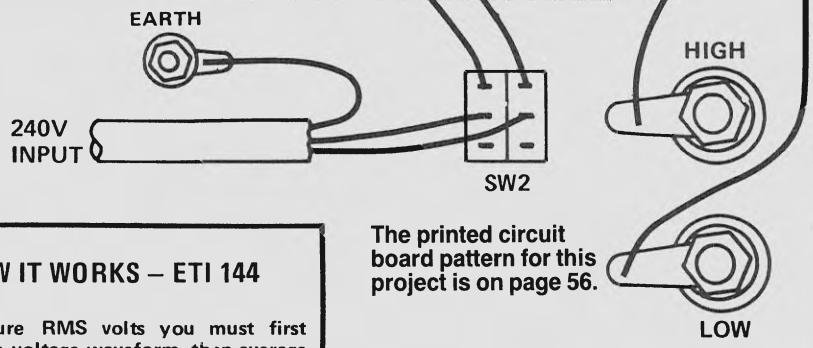
Half power is therefore 120 W. The voltage corresponding to this is given by:—

$$E = \sqrt{P \times R} \text{ or } 170 \text{ V (rms)}$$

On a 'normal' meter this will read 120V, — an error of 30%. ▶



Component overlay. Note that the plastic cover has been removed from the transformer to allow mounting under the meter.



Construction

Assemble the pc board according to the overlay diagram, starting with the low height components. Do not fit the switch or the transformer yet. Watch the polarity and orientation of the components before soldering.

Before the transformer can be used the plastic cover and base have to be removed to reduce its height. This can be easily done using a small bladed screwdriver. Do not remove the internal plastic cover over the windings. The transformer can now be mounted and soldered in place keeping it as close as possible to the board.

The rotary switch specified (C & K 1054) is a pc-mounting type but may not be as readily available as the CK1034 type which has wiring connections. This can be used however if the very ends of the terminals are cut off carefully When fitting it to the pcb ensure that the No. 1 pin is toward the top of the board. Do not solder yet.

Fit the Scotchcal panel to the aluminium front panel and drill all the holes. Fit the meter to the panel. Assemble the power switch and terminal posts to the panel. Attach wires, about 100 mm long, to the terminal posts and also wire up the power switch. Earth the front panel using one of the meter retaining screws and leave about 50 mm of wire on the two outputs from the switch.

HOW IT WORKS – ETI 144

To measure RMS volts you must first square the voltage waveform, then average it and finally take the square root of that average. In this unit we electronically square and average the input but we use the meter scale to take the square root.

The input voltage is divided by the input network such that the input IC1 is 0.47 volts (dc or RMS) for full scale deflection. IC1 provides buffering and a gain of two.

Squaring of the output of IC1 is done by IC2 (1494), a four quadrant multiplier, which gives a current output proportional to the product of the voltages at its two inputs (pin 9 and 10). As we are feeding the same signal into both inputs the result is the square function.

The output of this IC is a current which is converted to a voltage by IC3 which also provides the averaging network (C3, R32). its output drives the meter whose scale is a square root function.

Adjustments are provided for the input offset of IC2 (RV1) output offset (RV2) and overall calibration (RV3).

As the power requirement of all the ICs is +/– 15 V we use a mains supply and three-terminal regulators. Current drain is about 15 mA on both supplies.

The printed circuit board pattern for this project is on page 56.

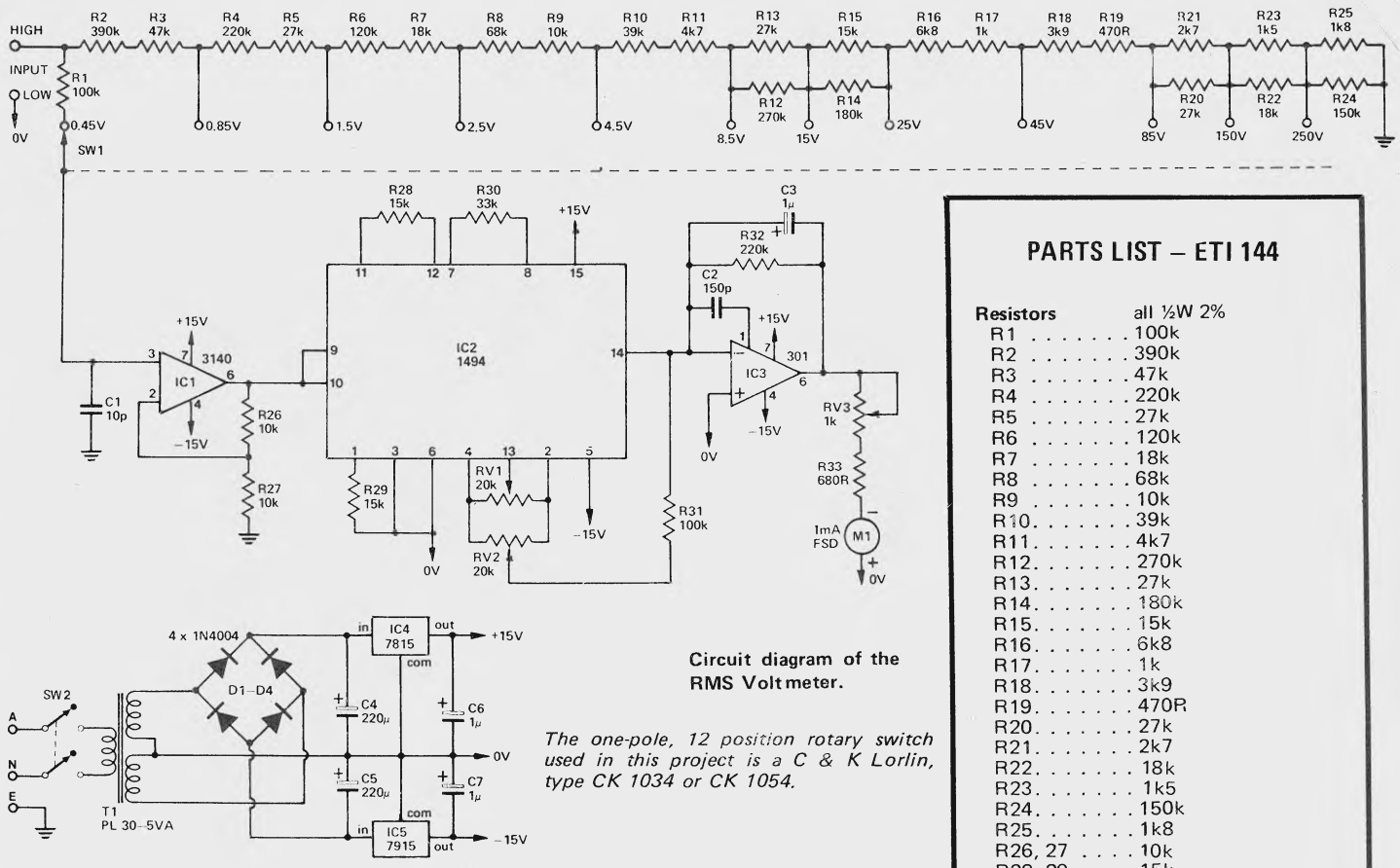
Now fit the pc board to the meter leaving the spring washers on the meter side of the board giving extra space to the front panel. As the switch now lines up with the front panel it can be soldered in place.

Connect the wires from the terminals to their position on the pc board. The 240 V wires from the switch come around the edge of the board and solder directly onto the terminals of the transformer. These connections should be covered with epoxy to prevent personal contact.

The meter scale can be fitted to the meter as follows:

Remove the clear cover from the meter (it clips on) then, carefully remove the existing scale. The scale should be sprayed white and allowed to dry.

Cut the Scotchcal to the borders marked, peel back the plastic a little and cut off about 5-10 mm of paper backing on one edge.



Circuit diagram of the RMS Voltmeter.

The one-pole, 12 position rotary switch used in this project is a C & K Lorlin, type CK 1034 or CK 1054.

ETI 144 EXPANDED SCALE RMS VOLTMETER

SPECIFICATIONS

Input range	150 mV to 270 V in 12 ranges, 5 dB apart
Accuracy	+/- 2% FSD
Crest factor	maximum, 10
Frequency response	dc to 50 kHz (sine wave)
Input impedance	1 M
Meter type	moving coil, RMS volts, expanded scale calibration

PARTS LIST – ETI 144

Resistors all ½W 2%

R1 . . . . . 100k
R2 . . . . . 390k
R3 . . . . . 47k
R4 . . . . . 220k
R5 . . . . . 27k
R6 . . . . . 120k
R7 . . . . . 18k
R8 . . . . . 68k
R9 . . . . . 10k
R10 . . . . . 39k
R11 . . . . . 4k7
R12 . . . . . 270k
R13 . . . . . 27k
R14 . . . . . 180k
R15 . . . . . 15k
R16 . . . . . 6k8
R17 . . . . . 1k
R18 . . . . . 3k9
R19 . . . . . 470R
R20 . . . . . 27k
R21 . . . . . 2k7
R22 . . . . . 18k
R23 . . . . . 1k5
R24 . . . . . 150k
R25 . . . . . 1k8
R26, 27 . . . . 10k
R28, 29 . . . . 15k
R30 . . . . . 33k
R31 . . . . . 100k
R32 . . . . . 220k
R33 . . . . . 680R

Potentiometers

RV1, 2 . . . . 20k 10 turn trim
R3 . . . . . 1k 10 turn trim

Capacitors

C1 . . . . . .10p ceramic
C2 . . . . . .150p ceramic
C3 . . . . . .1µ 35V tantalum
C4, 5 . . . . . .220µ 35V electrolytic
C6, 7 . . . . . .1µ 35V tantalum

Semiconductors

IC1 . . . . . CA3140
IC2 . . . . . MC1494
IC3 . . . . . LM301A
IC4 7815
IC5 7915

D1–D4. . . . . IN4004

Miscellaneous

PC board ETI 144
Transformer PL30/5VA (Ferguson)
Meter TD118, 1mA FSD (University)
Meter scale to suit
Zippy box 196 x 113 x 60 mm
Scotchcal panel
2 pole power switch
1 pole 12 position rotary (see text)
Knob to suit
3 core flex, plug and clamp
2 terminal posts

The Scotchcal panel can now be placed on the meter scale and lined up while holding the sticky edge off the panel. Now press down the sticky edge to locate the panel then fold it back on itself to allow the rest of the backing sheet to be removed. Press the panel down from the edge already fixed removing any air bubbles from under it.

The scale can now be refitted to the meter and the cover placed back. ▶

Alignment and calibration

Equipment needed:
variable dc power supply
accurate dc voltmeter
two-pole change over switch

Connect the power supply to the input terminals, via the switch, connected to give polarity reversal. Switch on the unit and with no input voltage adjust RV2 to give a reading about a quarter of the way up the scale.

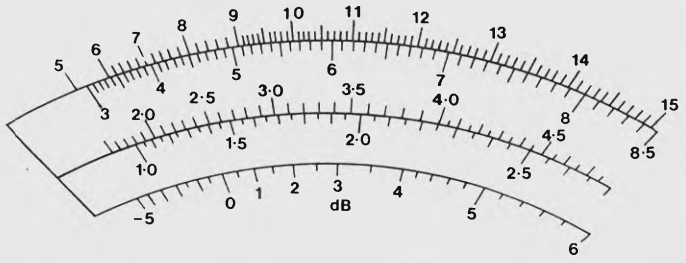
Allow the unit about five minutes to warm up and stabilize. You could check to see if the internal supplies are giving the correct voltages while you wait.

Now, switch to the 15 volt range and apply about five or six volts to the input. Reverse the polarity of the input and note the change in the reading. Adjust RV1 until there is no difference, irrespective of polarity.

It will probably be necessary to adjust RV2 again to keep the reading on the scale. Note that it is not the actual reading that is important just that both polarities are the same. Increase the voltage to around 14 volts to ensure the adjustment is correct.

Now, with no input voltage adjust RV2 to give a zero reading. Apply 14 volts and adjust RV3 to read 14 volts. Adjustment is now complete.

EXPANDED SCALE RMS VOLTMETER

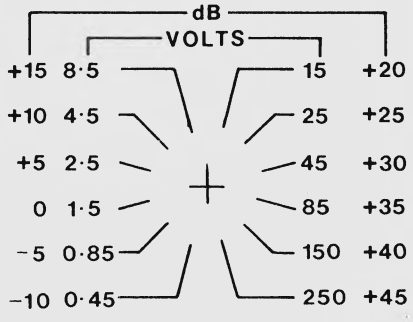


Note
Peak input voltage should not exceed 5 times F.S.D.

1mA F.S.D.

Both of these drawings are reproduced full size so that, if you wish, you can cut them out and use them directly.

eti 144



HIGH

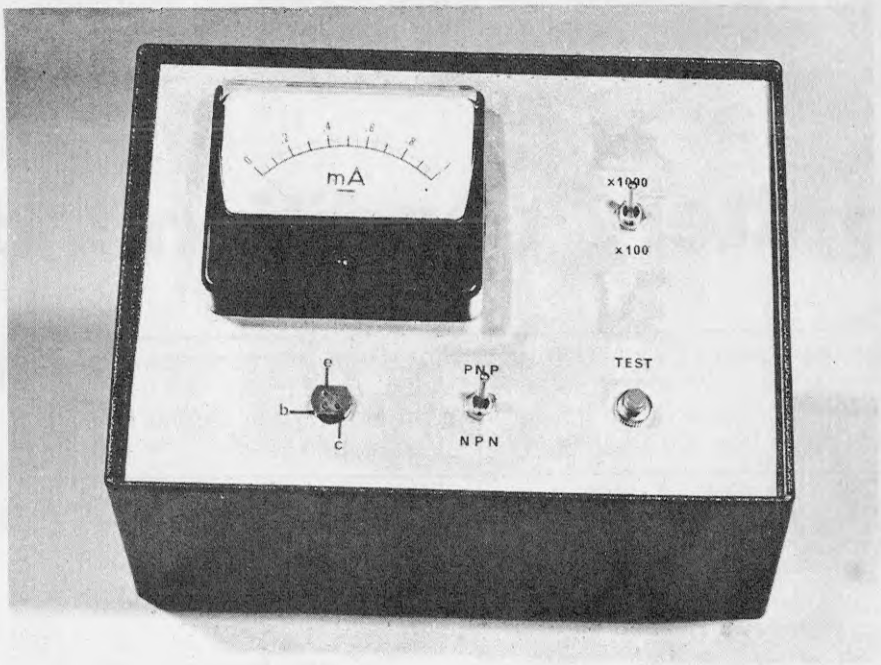
ON

LOW

OFF

Transistor tester

Measure and test your transistors with this easily built device.



The transistor tester mounted in a metal case.

EXPERIMENTERS will frequently use the same transistors in a whole sequence of experimental circuits, for recovering and re-using such components saves considerable outlay.

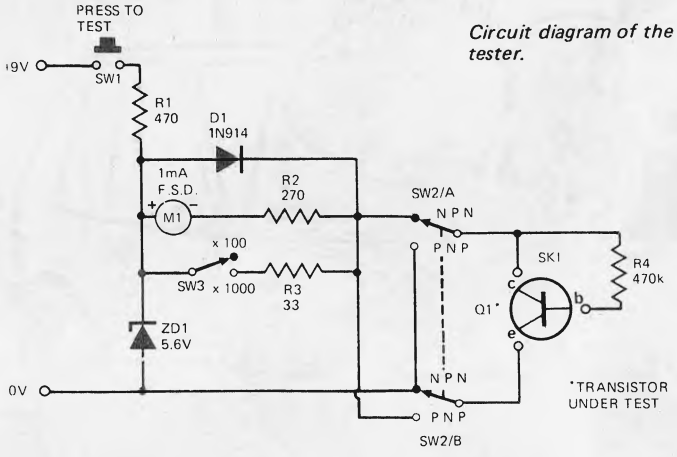
But semiconductors are easily damaged — by incorrect operating conditions — or by excessive application of heat when soldering.

Only too often a malfunctioning experimental circuit will be checked and rechecked before one realises that a transistor is dead.

A transistor tester will save hours of such frustrating and unproductive effort.

Transistors can often be bought cheaply in bulk — usually in unmarked and untested lots — or recovered from old computer boards. Here again a transistor tester will prove invaluable in eliminating the faulty bits.

The simple transistor tester described in this project not only sorts out the good from the bad but indicates also the approximate gain (β) of the transistor. This is a most useful feature for those circuits where transistors need to be matched. Two ranges of gain (beta) are provided, 0-100, and 0-1000. The tester may also be used to check transistor polarity.



Circuit diagram of the ETI transistor tester.

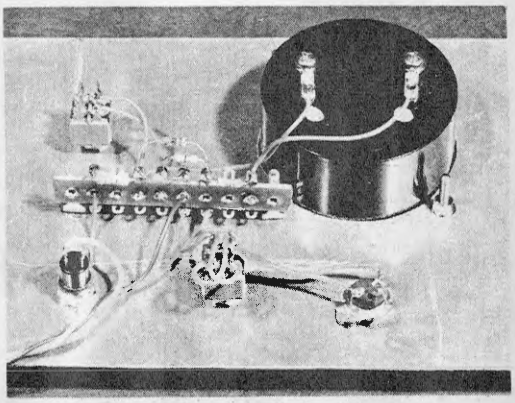
HOW IT WORKS

Operation of the tester is very simple. The meter, M1, monitors the collector current of the transistor under test whilst R4 supplies a current of about 10 μA into the base of the test transistor. Thus, on the 100β range, the maximum collector current will be 1 mA and, on the 1000β range, 10 mA. Switch SW3 therefore changes the meter sensitivity according to the beta range selected.

The meter is protected by means of D1 against damage due to test transistors being shorted. The zener diode ZD1 stabilizes the battery voltage to 5.6V.

PARTS LIST — Transistor Tester — ETI 222

R3 Resistor 33Ω ½ watt 5%
R2 Resistor 270Ω ½ watt 5%
R1 Resistor 470Ω ½ watt 5%
R4 Resistor 470k ½ watt 5%
D1 Diode IN914
ZD1 Zener diode BZY88C5V6
SW1 Push button push-to-make
SW2 Switch toggle DPST
SW3 Switch toggle SPST
9V battery
M1 Meter 1mA movement
SK1 Socket T05 transistor type
Metal case or minibox



The construction method may readily be seen from this photograph of the back of the front panel.

Battery condition indicator

Ever been caught by a battery that went flat at an embarrassing moment – like when you've just offered a friend a lift? The conversation goes a little flat when you're both riding the bus to work, 20 minutes late. Jonathan Scott found a solution . . .

THE OLD, RELIABLE lead-acid battery may be way ahead of what ever is in second place for vehicle electrical systems, but they do need a 'weather eye' kept on them. Particularly if they're out of warranty. The same applies to 'reconditioned' batteries, so often found in secondhand vehicles of some age.

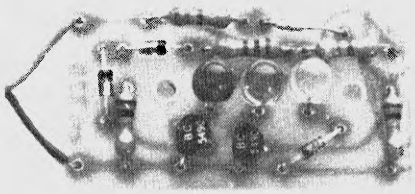
That's the problem with cars – running out of petrol and running out of battery produces the same heart-rending result. Immobility.

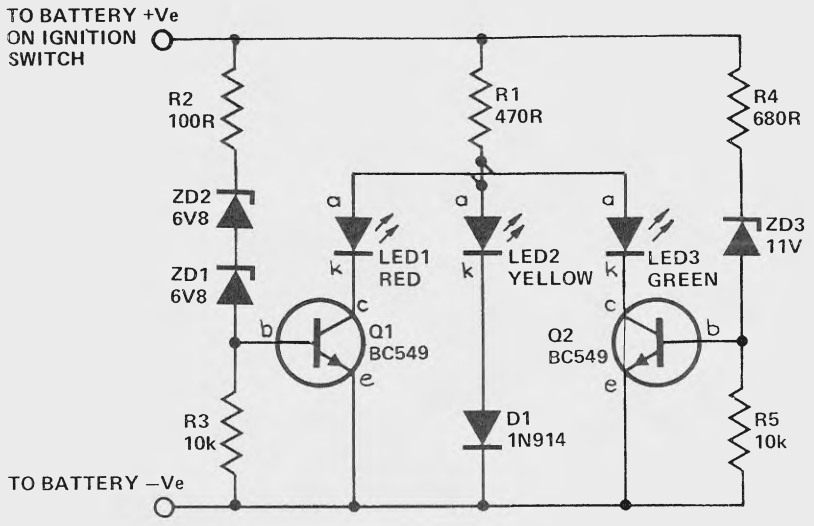
Most vehicles have a petrol gauge. Few have an equivalent for the battery. Many 'older' cars included a 'charging current' meter. This told you something about the car's generator-regulator and required some interpretation to figure out whether the battery was in good health.

Probably the best way to check on the state of your battery is to use a hydrometer. However, hydrometers have a number of drawbacks. Being made of glass, they're fragile and can't be used while a car is in motion. The small amount of battery acid that remains on them presents a storage problem – the drips and fumes attack most metals and materials. They're okay for the corner garage but justifying their cost, for the occasional use they get in home workshops, is not always possible.

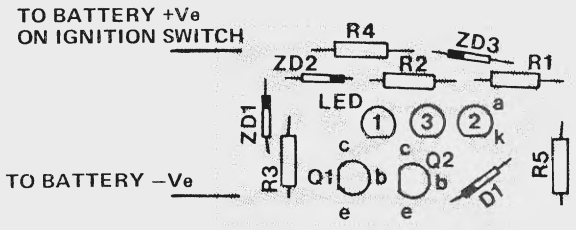
Another method of testing battery condition is by checking the voltage 'on load'. A lead-acid vehicle battery in a reasonable state of charge will have a terminal voltage under normal working load somewhere between 11.6 and 14.2 volts. When a battery shows a terminal voltage below 11.6 volts its capacity is markedly decreased and it will discharge fairly quickly. Like as not, it won't turn the starter motor for very long! On the other hand, if the voltage on load is above 14.5 volts then the battery is definitely fully charged! However, if it remains that way for any length of time while the car is on the road, the vehicle's alternator-regulator system is faulty and the battery may be damaged by overcharging.

Reading the battery voltage can be done in a number of ways. You could use a digital panel meter, set up as a voltmeter. Their drawback is that they cost nearly ten times as much as a hydrometer! The next best method is to use an 'expanded-scale voltmeter'. Reading the voltage range between 11 and 15 volts on a meter face calibrated 0-16 volts is a squint-and-peer exercise. On a 0-30 volts scale, as used on many modern multimeters, it's worse. A meter which reads between 11 volts at the low end of the scale and 16 volts at the high end is ideal. Hence, the term 'expanded-scale'.





The circuit diagram and component overlay (below). During construction, make sure all of the diodes and LEDs are the right way round.



HOW IT WORKS – ETI 320

This circuit depends for its operation upon the different voltage drops across different colour LEDs.

At 20 mA the voltage drops across red, yellow and green LEDs are typically 1.7, 3.0 and 2.3 volts respectively. When the vehicle battery voltage is too low to cause either ZD1/ZD2 or ZD3 to conduct, Q1 and Q2 are held off by R3 and R5. Under these conditions the yellow LED is forward biased and conducts via D1 producing a potential of about 3.7 volts at point A (see circuit diagram). When the supply rises above about 11.6 volts ZD3 conducts, biasing Q2 on. By virtue of its lower voltage requirements the green LED conducts, reducing the voltage at point A to approximately 2.6 volts. This is not enough to bias D1/LED3 on, so the yellow LED goes off. The green LED 'steals' the bias from the yellow LED. When the supply rises above about 14.2 volts, Q1 is biased on and the red LED 'steals' the bias from the green. The potential at point A falls to two volts and only the red LED conducts.

R1 limits the current through the LEDs. R2 and R4 limit the base currents into Q1 and Q2.

PARTS LIST – ETI 320

Resistors all ¼W, 5%

R1	470R
R2	100R
R3, R5	10k
R4	680R

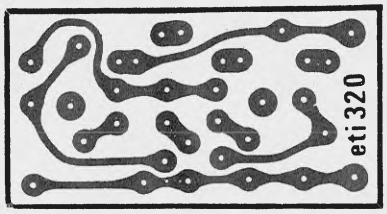
Semiconductors

D1	1N914
ZD1, ZD2	6V8 400 mW zener
ZD3	11V 400 mW zener
Q1, Q2	BC547,8,9 or BC107, 8, 9 or common silicon NPN type

Miscellaneous

pcb ETI 320

Aluminium angle bracket for under-dash mounting.



The printed circuit board pattern

However, you don't want to be peering at a meter on the dash board when you're driving through traffic. The range of voltage over which your battery is healthy is some two volts. An indicator which simply requires the occasional glance, and needs no 'interpretation', is what is really needed.

With this project, that's exactly what we've done.

Go, caution, stop

We have devised a simple circuit that indicates as follows:

Yellow:	battery 'low'
Green:	battery okay
Red:	battery overcharging

When the battery voltage is below 11.6 volts, a yellow indicator lights. This indicates the battery is most likely undercharged or a heavy load (such as high power driving lights) is drawing excess current. When it is between 11.7 and about 14.2 volts the green indicator lights, letting you know all is sweet. If the red indicator lights, as it will if the voltage rises above 14.2 volts, maybe the vehicle's voltage regulator needs adjusting or there is some other problem.

The circuit

The circuit is ingeniously simple, having barely a handful of parts. Reliability should be excellent.

We actually started out with a somewhat complex circuit. It used only two indicators and required you to 'interpret' what was happening. In trying to convert that to a yellow-green-red style of indication it sort of grew like topsy. This circuit had four transistors, a dozen resistors etc and didn't look at all attractive as a simple project that the average hobbyist or even handyman could build one Saturday afternoon and get going immediately. A rival circuit was devised by another staff member using a common IC. This sparked a controversy as to which was the better! Certainly, both did the job required . . . but maybe there was a simpler method.

It was discovered that different coloured light emitting diodes (LEDs), which we had decided to use for the indicators in the project, had different voltage drops when run at the same current. Seizing on this idea, the original circuit (four transistors, a dozen resistors . . .) was modified to exploit this characteristic and the simple circuit you see here was the result.

Construction

Construction is straightforward. If you haven't soldered electronic components

before – and this project was designed for the motorist/handyman as well as electronics enthusiasts – then we suggest you practice on something before tackling this project. Soldering is one of those things like swimming or riding a bicycle, or sex – it's okay once you've done it once or twice but you don't practice out on the street!

We recommend you use the printed circuit board designed for this project. The actual layout of the components themselves is not critical but a printed circuit board reduces the possibility of errors.

It is best to mount and solder the resistors first. Follow this by soldering in the diodes D1 and the zener diodes ZD1, ZD2 and ZD3. Carefully follow the accompanying component overlay making sure the diodes are all inserted the correct way around. Next, mount the transistors, again referring to the overlay, checking to see they are inserted correctly before soldering.

Finally, mount the light emitting diodes. These too may only be inserted one way. Check with the component overlay and connection diagrams. Make sure they are in the correct sequence. On the component overlay, LED 1 is the **red** LED, located at the left. The **yellow** LED is on the right, marked with a '2'. The green LED, marked '3' is between them.

The circuit could be tested at this stage if you have a variable power supply, or access to one. Simply vary the voltage across the range between 11 and 16 volts and note whether the LEDs light up in the correct sequence and close to the voltages indicated.

Mounting

As vehicles vary so much in dash panel layout, we can only make general suggestions.

Clearly, the indicator should be mounted such that the three LEDs are not in direct sunlight. A low part of the dash, but make sure it's readily visible from your normal driving position, will pretty well ensure the display may be easily read during the daytime. Alternatively, if you have an 'overhung' dash, or a portion which overhangs (usually where the instruments are mounted anyway), then a suitable position will generally suggest itself.

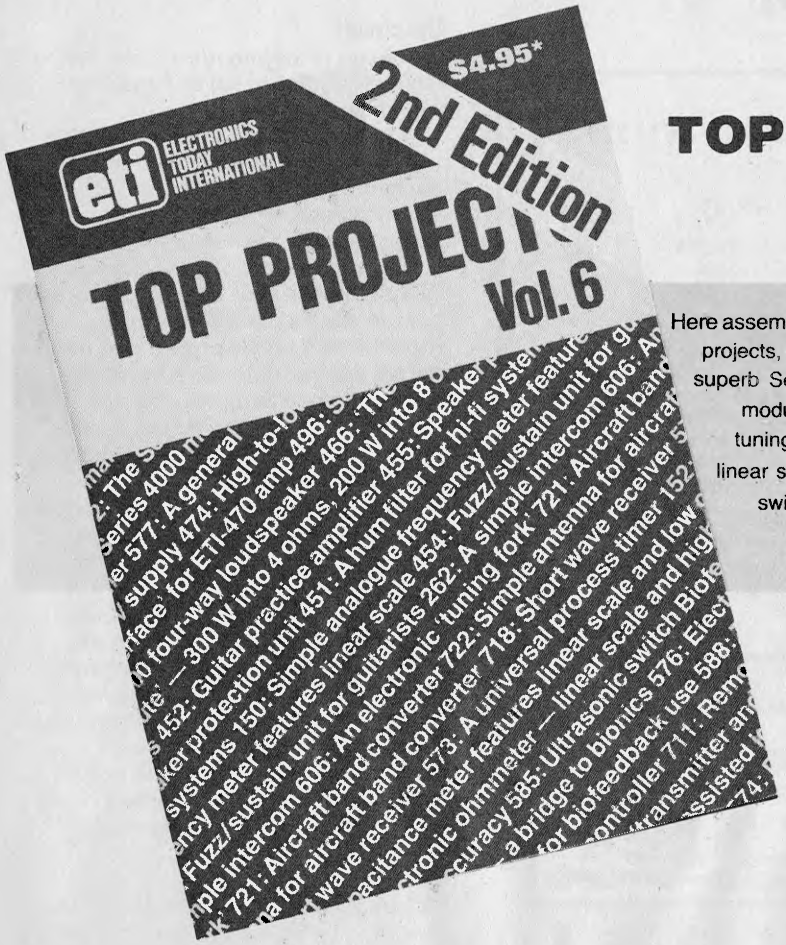
Exact mechanical details will have to be determined according to your particular situation. Two holes are provided in the pc board for mounting bolts. Alternatively, the whole assembly may be mounted from the LEDs. Three LED holders inserted through part of the dash panel, or an escutcheon plate mounted on the dash, will hold the LEDs quite securely. Providing the leads on the LEDs are fairly short, the pc board will place little strain on them and the assembly should be mechanically secure.

Connection

The indicator may be installed in vehicles having positive or negative earth electrical systems.

The component overlay shows the connection for a **negative** earth vehicle. The 'battery +ve' lead goes to the ignition switch – the indicator only operates when the vehicle is being used – the battery negative lead should be taken to a good 'earth' point on the vehicle frame.

For a **positive** earth vehicle, the lead marked 'battery –ve' goes to the ignition switch connection, while the 'battery +ve' lead goes to the vehicle frame.



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Microwave oven leak detector

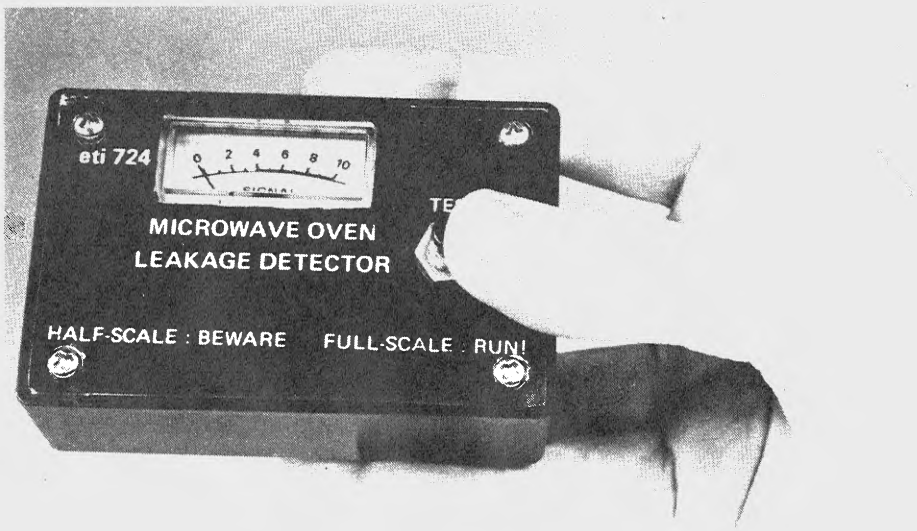
While microwave ovens are generally well-designed and safe to use, the human factor (even Murphy's Law) can thwart the manufacturer's efforts and possible unsafe levels of microwave energy may be radiated without warning. Simple and inexpensive to build, this project will indicate if your oven is safe . . . or not.

Jonathan Scott

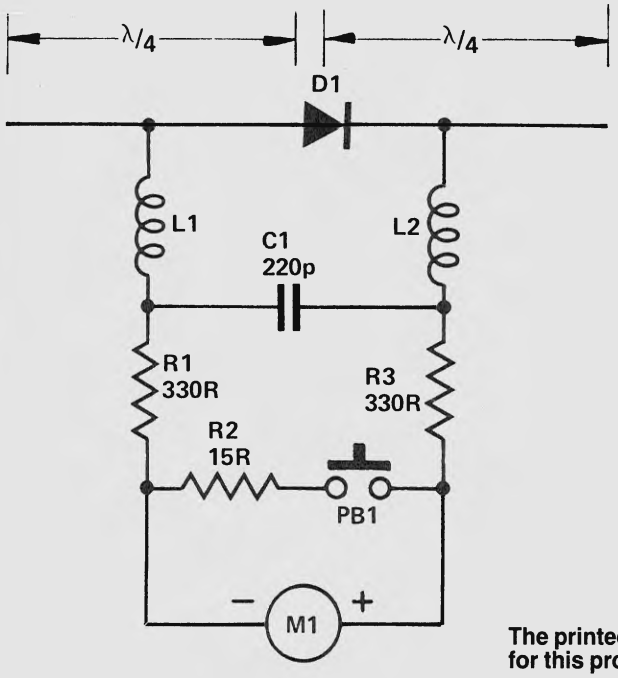
THE MICROWAVE oven is one of the most recent examples of advanced technology finding application in the home. Many thousand such devices are sold for domestic use in Australia alone each year, while commercial units have long been found in restaurants and snack-bars.

The microwave cooking method, while unlikely to usurp conventional cooking methods, has distinct advantages. It is usually quicker; two to five times quicker in fact. Because it heats the foods directly, but does not heat the bowl or container, the food can be left enclosed. The process is often cleaner and less utensil-consuming as a result. Because the energy penetrates below the surface of a lump of food and does not rely so completely on conduction, it can be used for rapid defrosting of foods. (See "How a microwave oven works").

Unfortunately, the microwave energy is quite dangerous. It must be carefully contained within the cooking chamber. The window is usually sealed to the radiation by a fine metal grille similar to heavy duty fly-screen. The door fits flush and firm, and the instructions warn against allowing any distortion of



The device is housed in a 'zippy' box, everything being attached to the front panel, held in place by the four screws. Our prototypes were calibrated through the kind assistance of the Electrical Engineering Department of Sydney University.



The printed circuit board artwork for this project is on page 58.

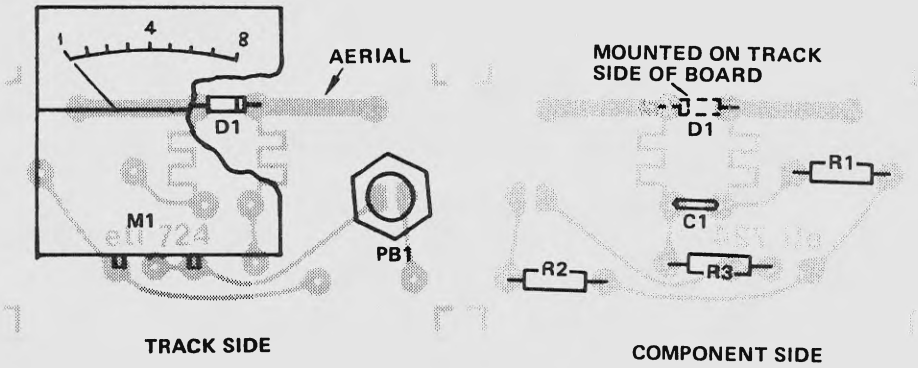
HOW IT WORKS – ETI 724

Operation is very simple. The device is completely passive and requires no batteries. It uses the radiated energy from the oven to deflect a meter directly.

The pc board dipole, when exposed to microwave radiation of about 2.5 GHz, develops an ac voltage across D1. When the diode is positively biased the diode conducts, shorting the dipole. When reverse biased it isolates, thus leaving a net voltage on the diode. This DC component is filtered by L1, L2 and C1.

The amplitude of the dc component varies somewhat with the type of radiation from the oven – CW or pulsed, depending upon the supply rectification and filtering used with the magnetron. It will also vary with distance, of course. The Australian safety limit is 5 mW/cm^2 at a distance of 5 cm from the oven. R1, R2 and R3 define the sensitivity, the values chosen being suitable to produce FSD for 5 mW/cm^2 CW at the pc board plane with PB1 closed.

Some variation should be expected from unit to unit. This should not normally be of any concern, however, as a healthy oven will emit at least one order of magnitude less than the 5 mW level, and so the readout is unambiguous even when the unit is not the exact 5 cm from the oven surface.



Component overlays of both sides of the pc board. Note that the diode is mounted on the COPPER SIDE of the board. It is strongly recommended that the device is constructed using the pc board design shown so that results are consistent with the calibrated prototype.

PARTS LIST - ETI 724

Resistors
R1 . . . . . 330R
R2 . . . . . 15R
R3 . . . . . 330R

Capacitor
C1. . . . . 220p ceramic

Semiconductor
D1 . . . . . HP 5082–2800 Shottky Hot Carrier Diode

Miscellaneous
PB1. . . . . momentary push button
M1 . . . . . 250μa FSD Signal Strength meter
L1, L2 . . . . . Etched on pcb

ETI 724 pcb (includes L1, L2 and antenna).

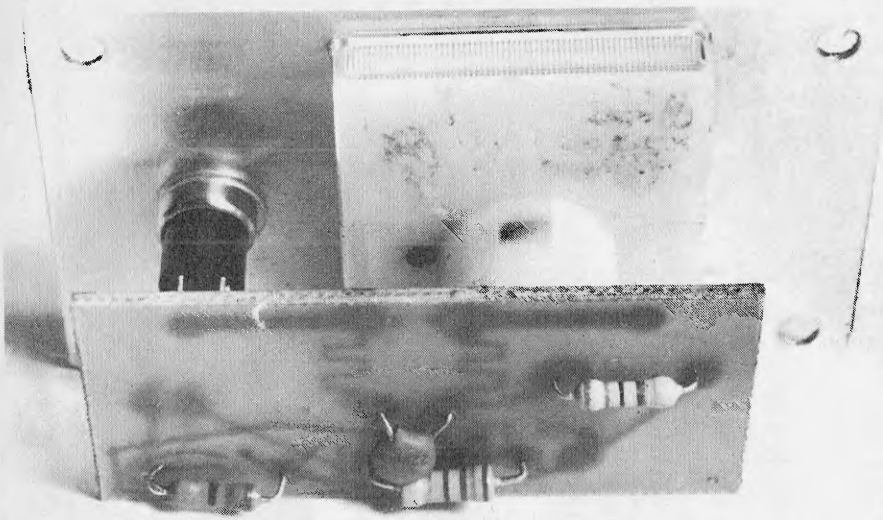
Plastic jiffy box (25 mm x 50 mm x 90 mm).

the door. All ovens have safety circuits preventing the power being applied with the door open. Some ovens have as many as five interlocks against accidental activation without correct door closure. They do not, unfortunately, incorporate an alarm which warns if a leak occurs. This can happen if the door is slightly bent by being closed on a lump of stray food or if damaged during a domestic fracas.

In view of these things it seems wise to have some additional method of checking for leakage.

Leak detectors

There are some commercial leak detectors available. The most common one is made by the CSIRO. This consists of some circuitry, including a LED, encapsulated in a clear plastic tube. Entirely passive in operation, it illuminates the LED if the integral 62 mm long dipole is exposed to radiation of approximately the safe recommended limit. The CSIRO device is the cheapest available and sells for around $15. In operation it is satisfactory, but has two drawbacks. Firstly, were the hot carrier diode to be destroyed, as could happen for any number of reasons, including being exposed to cook strength signal, a 'safe'



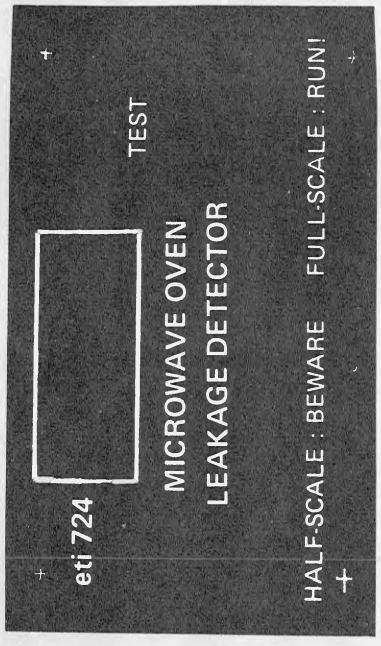
Internal view of the microwave oven leak detector shows the simplicity of construction.

report would always be given. In other words, the device cannot easily be checked. Secondly, the output is go/no-go. No indication of gradual increase in leakage is available.

So, if leakage from your oven has been gradually getting worse, you won't know until it reaches the level that trips the sensor (admittedly this may still be well below the harmful level).

Our design does not suffer from these drawbacks. The output is an analogue meter. This is set to read full-scale deflection (FSD) for a signal of approximately 5 mw/cm^2 in the 'test' mode. Hence, as little as 10% of the danger level can be read.

When the test button is released, the sensitivity increases by about an order of magnitude. In this condition the unit acts like a signal strength meter, and should show some deflection with the normal residual leakage of an oven. This confirms that it is working. We estimate that it should cost $10-$12, pc board included, as a kit. If you have upwards of $300 worth of oven, ten dollars is not a bad investment to insure the family jewels . . .



Construction

Unless you are very experienced with high frequency work already it is important to use the pc board. The antenna is printed onto the board and so, is inherently tuned sufficiently closely when the correct board is used. It is also convenient as the meter and button are soldered directly on the copper side and the whole assembly is self-contained.

No box at all is actually necessary, but if you choose to use one, ensure that it is not metallic except for the front panel. There are no flying leads, etc, so if need be, one could leave the whole circuit just as is, with no box.

We used a 25mm x 50 mm x 90 mm jiffy box which was just big enough inside.

Ensure that the diode and meter are soldered in the right way round. Also try to solder the diode neatly, as shown in the overlay. It should be soldered onto the copper side directly, flat against the pc board in the centre of the dipole. Use of the board and close adherence to our design will ensure that your unit is close to prototype sensitivity and will thus read true.

Using it

The meter is moved around the door rim with the oven operating, meter facing away, button depressed, the back parallel to the door and spaced approximately 40 mm from the surface.

When testing, it should be moved over the oven in each polarisation, just to be sure. To check if it is working, simply repeat the procedure without depressing the test button. Some erratic flicker of the needle should be evident, indicating correct operation. It can be left on top of the oven when not specifically being used, so that some drastic leak will cause deflection should that occur.

How a microwave oven works

There are several separate sections to a microwave oven. Firstly, there is a Magnetron, which is the heart of the system. This is a thermionic device incorporating a resonant cavity. It is an oscillator and will deliver power at super high frequencies (microwave ovens operate on 2.45 GHz). The oven has a power supply incorporating a number of safety interlocks preventing activation in unsafe circumstances.

There is a cooling system for the electronics, usually a fan. The cooking chamber has metal walls and some system of ventilation to remove steam, etc. The one fan is often used to cool the electronics as well as ventilate the cooking chamber. A duct (waveguide) transfers the microwave energy to the chamber from the magnetron. Some form of disperser spreads the energy and prevents standing waves within the chamber. This is either a rotating platform moving the food or a set of vanes in the chamber ceiling reflecting the beam about. (This is often driven by the fan motor or even the stream of cooling-ventilating air).

Finally, a control panel allows varying degrees of automatic control of the RF power. This always includes a timer and a door interlock.

Water is the primary microwave absorbing agent in food. Dry food and glass or plastic containers are substantially unheated by the radiation. The energy can penetrate to a depth of about 20 mm effectively, though this varies markedly with the food.

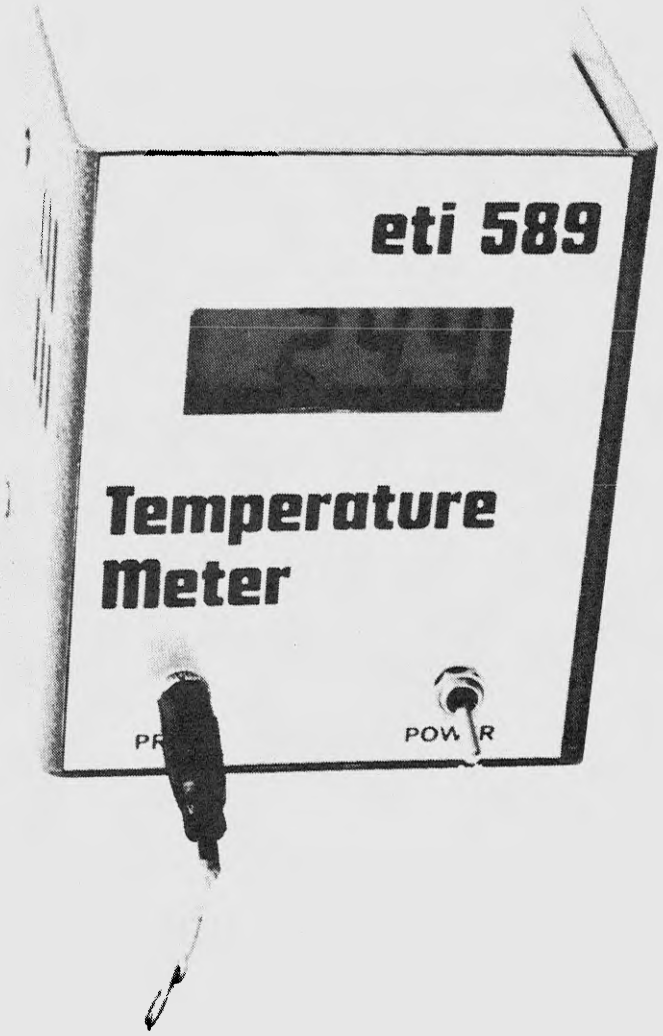
Domestic ovens consume about 1200 watts altogether, of which about half appears as microwave power in the food chamber. This, considering the mode of absorption, is considerably more efficient than an ordinary oven which is why the cooking speed is so rapid.

Digital temperature meter

This simple yet accurate temperature meter will find many uses in the laboratory or home. It utilizes the digital panel meter described on page 23.

THE RELIABILITY OF electronic circuits in the days of valves was, to say the least, poor by today's standards. The introduction of transistors and integrated circuits increased reliability dramatically. One of the main reasons for this is the reduction of power dissipation and the resultant lowering of temperature. Devices and circuits are now designed to minimise power dissipation as this allows a higher component density while increasing reliability. However some circuits by their nature must dissipate high power and the semiconductor devices used must be kept within their temperature limits.

This temperature meter will allow transistor temperatures to be measured and the appropriate heatsink chosen. It is just as useful outside the electronic scene measuring liquid or gas temperature especially where the readout needs to be physically separate from the sensor.



Use and Accuracy

The accuracy of the unit depends on the calibration; provided it has been calibrated around the temperature at which it will be used, accuracy of 0.1 degree should be possible. We could not accurately check linearity but it appeared to be within 1° from 0° to 100°C.

However other errors will affect this reading. If measuring the surface temperature i.e. a heatsink temperature, there will be a temperature gradient between the surface and the junction of

SPECIFICATION – ETI 589

Temperature range	**– 50°C to +150°C** **– 60°F to +199.9°F**
Resolution	**0.1°C or F**
Sensor	**silicon diode**
Power consumption	**1.5mA @ 9 V dc**

the diode. Silicon grease should be used to minimise the surface-to-surface temperature difference. Also when measuring small objects, e.g. a TO-18 transistor, the probe will actually cool the device slightly. At high temperatures these effects could give an error of up to 5% (the reading is always less than the true value). If the probe is in a fluid, e.g. water or air this problem does not occur.

Construction

Assemble the panel meter as previously described but omitting the zener diodes and R6 and R7. The value of R1 has also been changed. The decimal point drive should be connected to the right-hand decimal point. The additional components can be assembled on a tag strip as shown.

We mounted our unit on a tag strip as shown in the photo. While we have not given any details, knocking up a case should be no problem. For a power supply we used eight penlight Nicad cells giving a 10 V supply. If dry batteries are used six penlight cells are recommended although a 216-type 9 V transistor battery will give about 300 hours of operation.

The sensor should be mounted in a probe as shown in Fig. 1 if other than air temperature will be measured. This provides the electrical insulation needed for working in liquids etc. It should be noted however that the quick dry epoxies are not normally good near or above 100°C and if higher temperatures than this are expected one of the slow dry epoxies should be used.

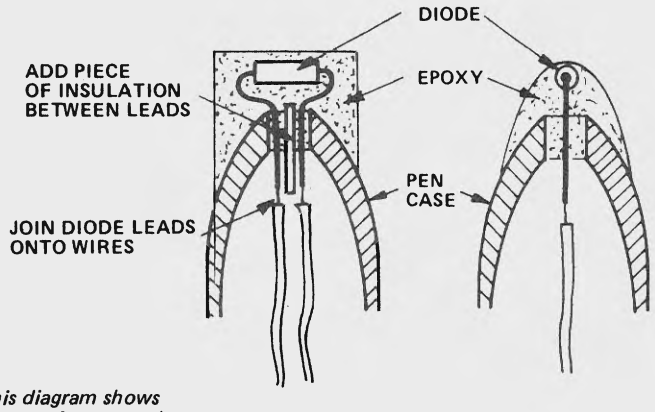


Fig. 1. This diagram shows how the sensor is mounted into a ball-point pen casing or similar.

Calibration

To calibrate this unit two accurately known temperatures are required, one of which is preferably zero degrees and the second in the area where the meter will normally be used and highest accuracy is required. For a general-purpose unit 100°C is suitable. The easiest way of obtaining these references is by heating or cooling a container of distilled water. However temperature gradients can cause problems, especially at zero degrees.

One method of obtaining water at exactly zero degrees is to use a test tube of distilled water in a flask of iced water and allowing it to cool to near zero. Now by adding salt to the iced water its temperature can be lowered to below zero. If you are very careful, the test tube water will also drop below zero without freezing (you should be able to get to about -2°C). However the slightest disturbance at this temperature will instantly cause some of the water to freeze and the remaining water to rise to exactly zero, providing an ideal reference.

For a hot reference the boiling point of distilled water is very close to 100°C especially if the container has a solid base and is evenly heated e.g. on an electric hotplate.

The actual calibration is done as follows:

1. In the 0°C reference adjust RV2 and RV3 until the unit reads zero.
2. In the hot reference adjust RV1 to give the correct reading.

This should be all the adjustment required.

If zero degrees is not available, e.g. if setting up for °F, the following method can be used:

1. In the cold reference use RV2 and RV3 to adjust reading to zero.
2. In the hot reference use RV1 to adjust the reading to indicate the temperature difference between the two standards. If freezing and boiling points are used, this will be 180°F.
3. Now, back in the cold bath, adjust RV2 and RV3 to give the correct reading.

No further adjustment should be required.

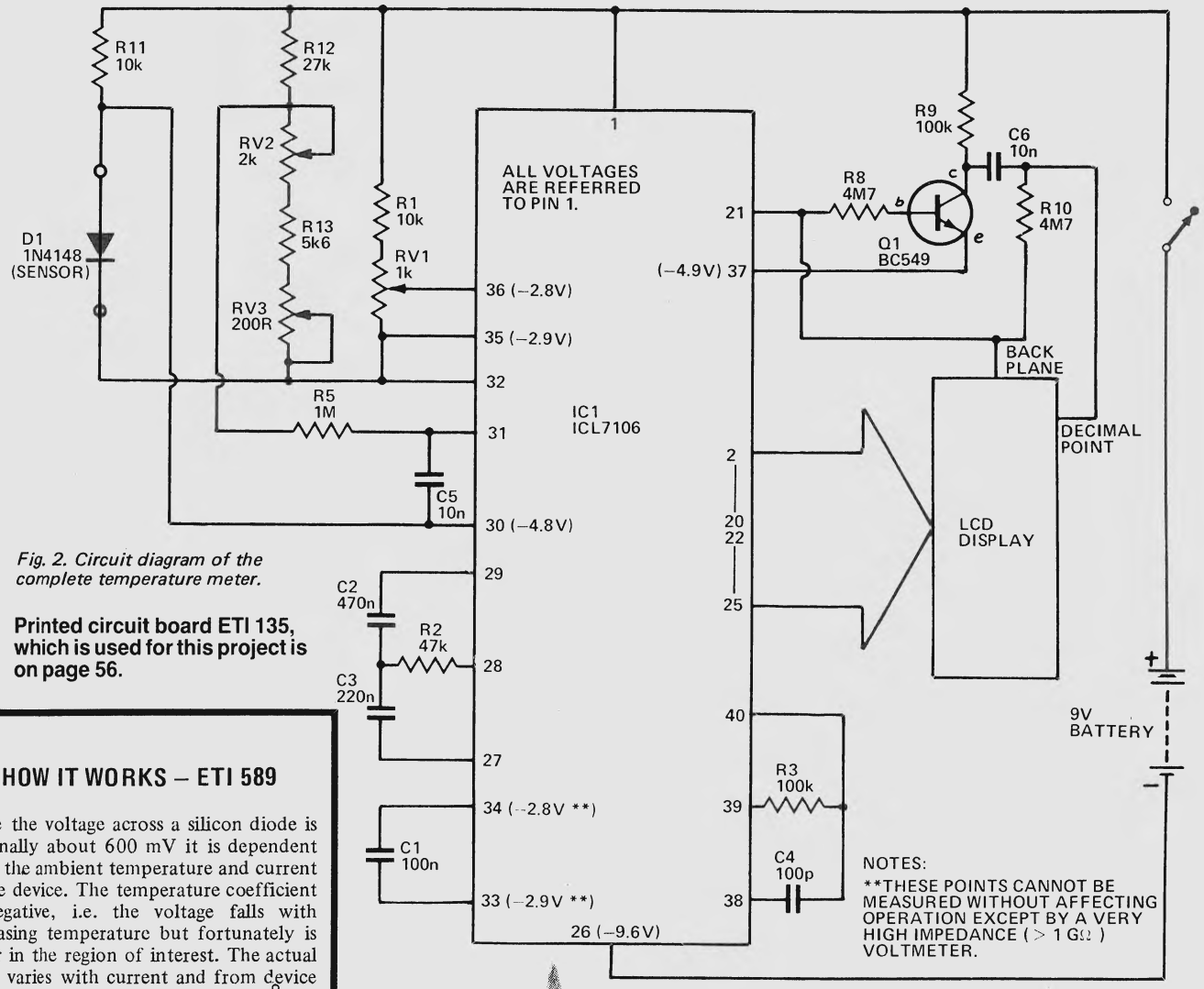


Fig. 2. Circuit diagram of the complete temperature meter.

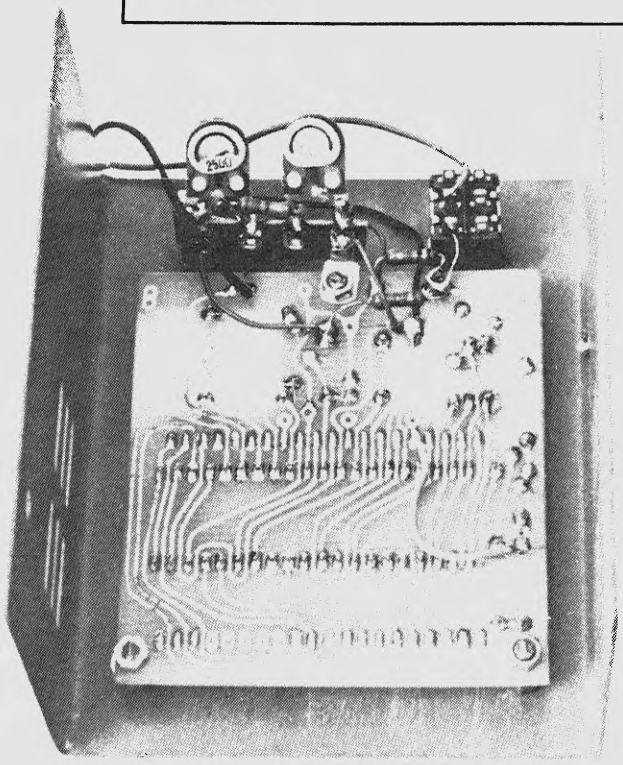
Printed circuit board ETI 135, which is used for this project is on page 56.

HOW IT WORKS – ETI 589

While the voltage across a silicon diode is nominally about 600 mV it is dependent upon the ambient temperature and current in the device. The temperature coefficient is negative, i.e. the voltage falls with increasing temperature but fortunately is linear in the region of interest. The actual value varies with current and from device to device, but is typically -2.2 mV/°C at 250 μA.

By measuring the voltage across the diode with a suitable offset voltage to balance the voltage at zero degrees an accurate temperature meter results. The digital panel meter described on page 23 has a stable reference voltage available (between pins 1 and 32) of about 2.9 V; with the 10k resistor R11 this provides a constant current for D1 (the sensor). The offset voltage is also derived from this reference voltage by R12, RV2 and RV3. The panel meter is used as a differential voltmeter and measures the potential difference between the offset voltage and the diode. We have used two trimpots in series in the offset adjustment to give better resolution. If desired a 10-turn trimpot can be used (2k2). Adjustment of the three potentiometers allows the meter to be calibrated in either °C or °F with the upper limit of 199.9°F due to the panel meter over-ranging.

The power supply is simply a 9 V battery, and so the zener diodes and dropping resistors described in the panel meter article should be omitted.



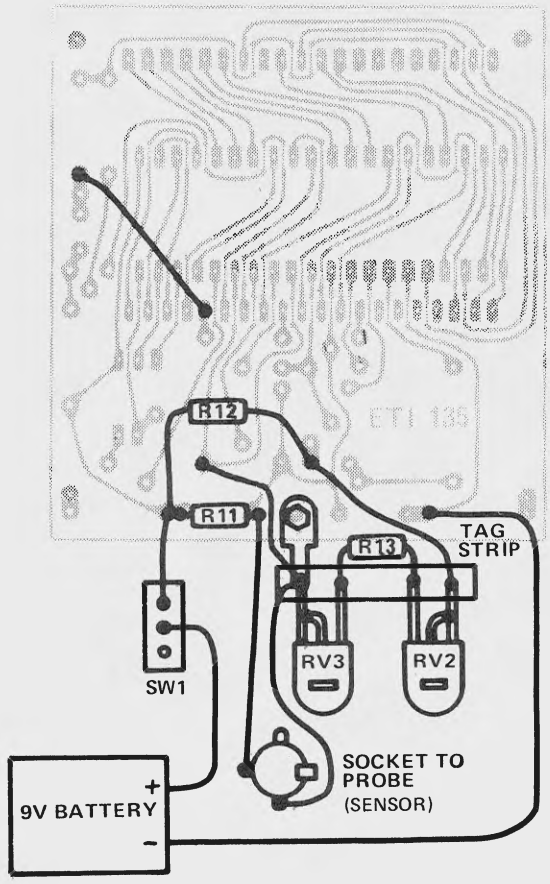


Fig. 3. The external components associated with the panel meter. For details of the panel meter see Project 135, page 23.

PARTS LIST – ETI 589

Resistors all ½ W, 5%
† R1 . . . . . 10k
* R2 . . . . . 47k
* R3 . . . . . 100k
R4 . . . . . not used
* R5 . . . . . 1M
R6 . . . . . not used
R7 . . . . . not used
R8 . . . . . 4M7
R9 . . . . . 100k
R10. . . . . 4M7
R11. . . . . 10k
R12. . . . . 27k
R13. . . . . 5k6

Potentiometer
* RV1 . . . . . 1k 10 turn trim
RV2 . . . . . 2k trim
RV3 . . . . . 200 trim

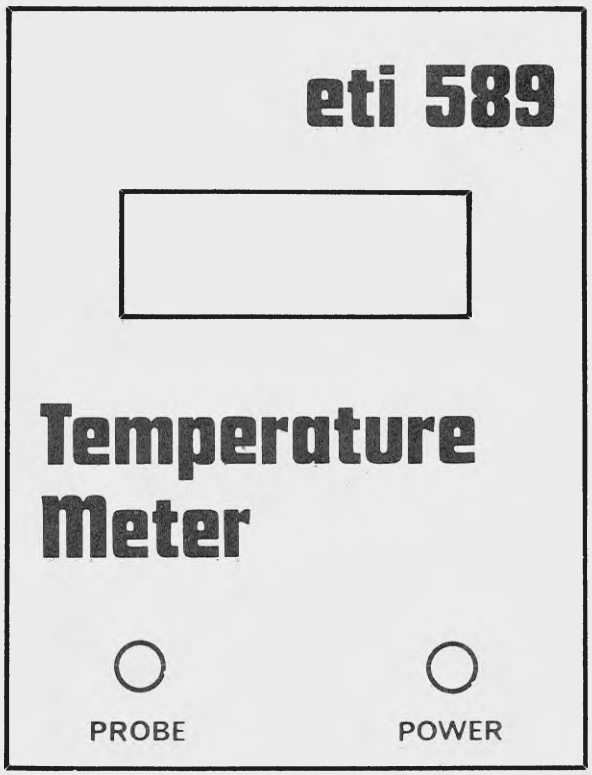
Capacitors
* C1. . . . . 100n polyester
* C2. . . . . 470n "
* C3. . . . . 220n "
* C4. . . . . 100p ceramic
C5. . . . . 10n polyester
C6. . . . . 10n "

Semiconductors
* IC1 . . . . . ICL7106
Q1 . . . . . BC549
D1 . . . . . 1N4148

Miscellaneous
PC board ETI 135
Tag strip
* LCD Display
* Socket for LCD display
Box
Switch
9V battery

* These components are supplied with the Intersil ICL7106 EV evaluation kit.

† This value has been changed from the original panel meter.



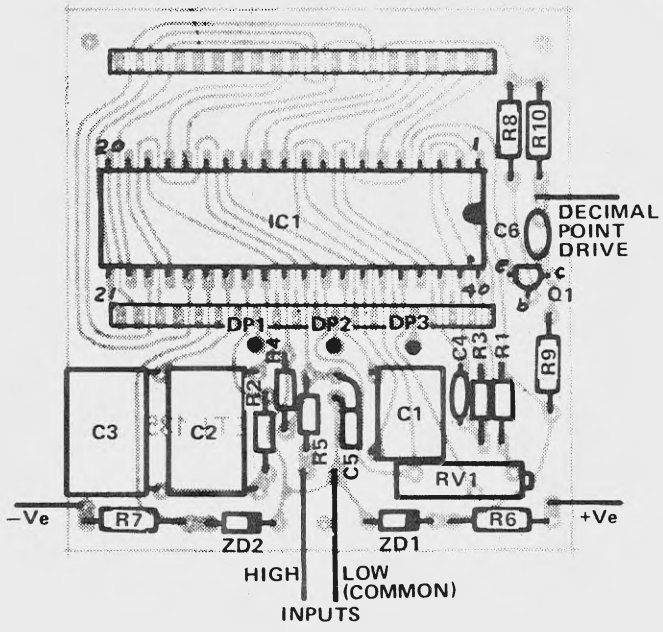


Fig. 4. The component overlay of the panel meter with the display removed. Note that for this project R4, 6, 7, ZD1, 2 and the external leads are not used.

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Tone burst generator

A valuable tool for testing loudspeakers.

TONE BURST testing is a technique which is rapidly gaining acceptance in a wide variety of applications. Typical applications are in testing of hydrophones, signal-to-noise in telephone channels, reverberation chamber testing and in the determination of peak distortion in loudspeakers. With loudspeakers, tone burst testing has the further advantage that the speakers may be tested with their maximum peak power level whilst keeping the average sound output level low enough to not annoy the neighbours — a considerable advantage indeed.

Some time ago our audio consultants, Louis Challis and Associates, asked us to build them a tone-burst generator and the resulting instrument has been used by them ever since with much success. The tone-burst test has been mentioned in several speaker reviews and, as a result, many people have asked for constructional details of this instrument.

DESIGN FEATURES

A tone burst must always be an integral number of cycles. If the burst is switched on or off part way through a cycle then undesirable transients will be produced that will mask the test results. Thus the burst must start and end exactly at the zero-crossing point of the sine wave in the burst.

In the original unit, designed for Louis Challis, preset times can be independently selected for the on and off periods of the burst with the exception that the burst time is automatically modified to give an integral number of cycles. The preselected on/off ratio, however, is independant of the burst frequency. To give the required control range, six switched ranges as well as a variable control are provided for both the on and off periods. Other features of the original unit are the ability to start at any point in the cycle as well as the zero crossing point, a phase-inverting switch to select either the positive or the negative half cycle first and an OFF LEVEL control to set a base tone level which is modified when the tone burst occurs. In addition the dc level of the output can be set and a switch is provided to select burst, pure tone or off as required.

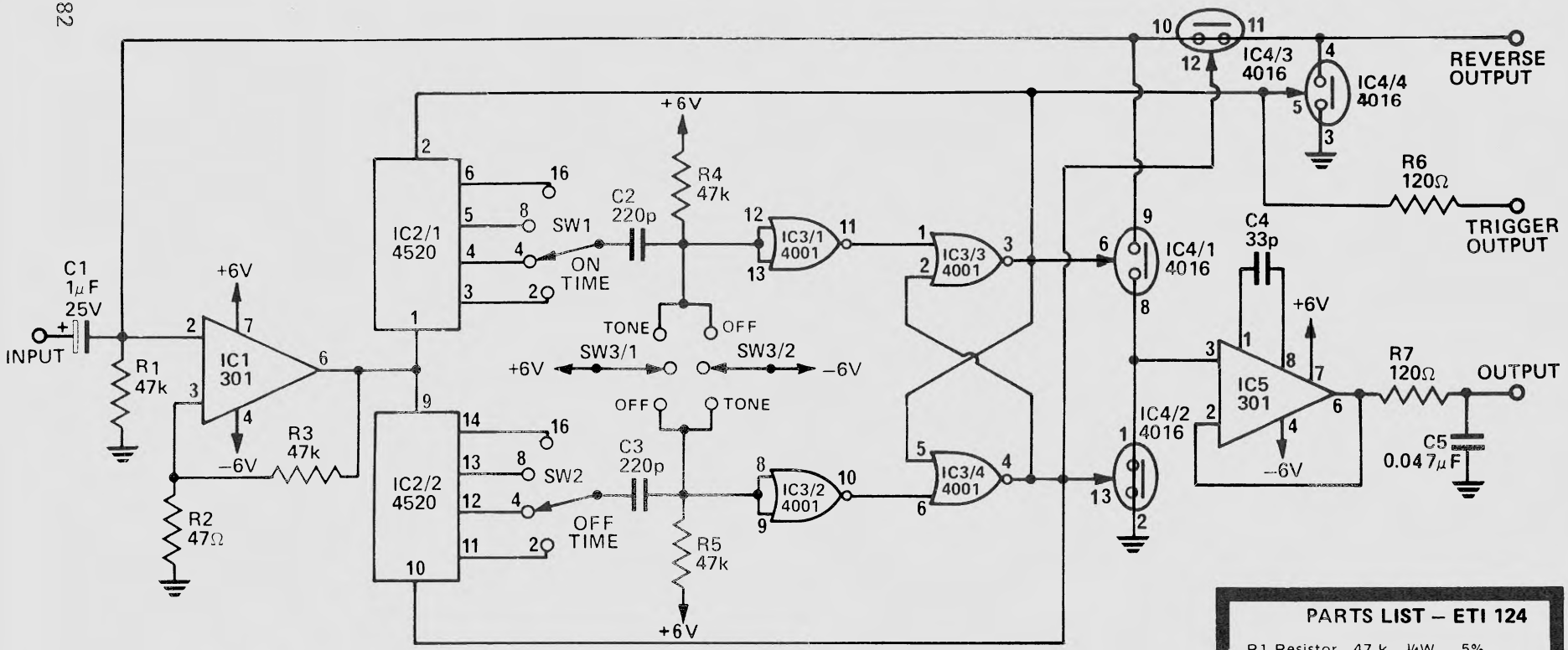
MEASURED PERFORMANCE

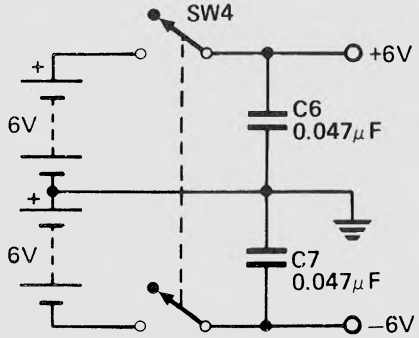
TONE BURST GENERATOR

On Time Cycles.	2,4,8 or 16
Off Time Cycles	2,4,8 or 16
Frequency Response 3 Hz – 300 kHz	+0 –3 dB
Distortion 3 V input at 1 kHz	<0.02%
Input Level Maximum	3 V RMS
Nominal range	100 mV to 1 V
Input Impedance	47 k
Output Noise Voltage with no input	<25 μV
Power Supply Current	4 mA

When it came to redesigning the unit as a project we decided that many of the features offered by the original design were unnecessary for the user concerned only with testing speakers. Hence the unit has been redesigned in a greatly simplified form.

Instead of using monostables to generate variable on/off times we now divide the input with a counter to

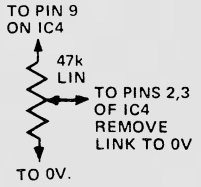




POWER RAILS OF IC2, IC3, AND IC4 NOT SHOWN
PIN 16 OF IC2 IS +6V
PIN 8 OF IC2 IS −6V
PIN 14 OF IC3 AND 4 IS +6V
PIN 7 OF IC3 AND 4 IS −6V
PIN 7 AND 15 OF IC2 ARE RESET PINS AND −6V

Fig. 1. Circuit diagram.

Fig. 4. How to add a potentiometer to the generator for burst-on-tone operation. That is the generator gives a continuous tone level with tone bursts of higher amplitude at intervals.

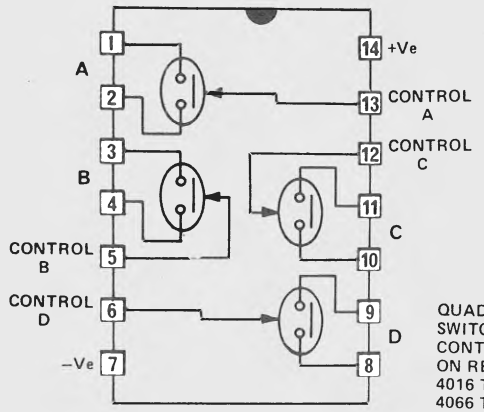


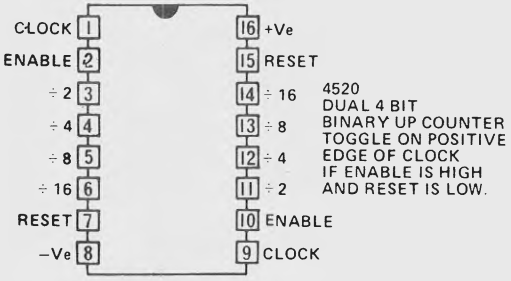
PARTS LIST – ETI 124

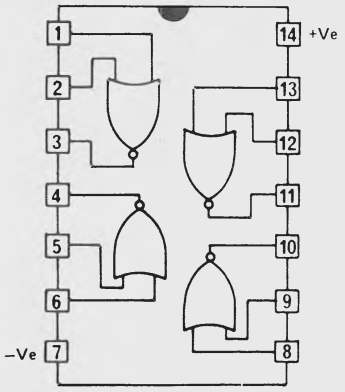
R1	Resistor	47 k	¼W	5%
R2	"	47 Ω	¼W	5%
R3	"	47 k	¼W	5%
R4	"	47 k	¼W	5%
R5	"	47 k	¼W	5%
R6	"	120	¼W	5%
R7	"	120	¼W	5%
C1	Capacitor	1 μF 25V electro		
C2	"	220 pF ceramic		
C3	"	220 pF ceramic		
C4	"	33 pF ceramic		
C5	"	0.047 μF polyester		
C6	"	0.047 μF polyester		
C7	"	0.047 μF polyester		
IC1	Integrated Circuit	LM 301A		
IC2	"	"		4520 (CMOS)
IC3	"	"		4001 (CMOS)
IC4	"	"		4016 (CMOS)
IC5	"	"		LM301A

SW1 Switch 1 pole 4 position rotary
SW2 Switch 1 pole 4 position rotary
SW3 Switch DPDT Toggle with centre off
SW4 Switch DPDT Toggle

PC Board ETI 124
8 AA size batteries
2 4-way battery holders and clips
Plastic case
Escutcheon
3 single RCA sockets
2 knobs







INPUTS		OUTPUT
A	B	
0	0	1
0	1	0
1	0	0
1	1	0

Fig. 3. Pin connections of the ICs used in the generator.

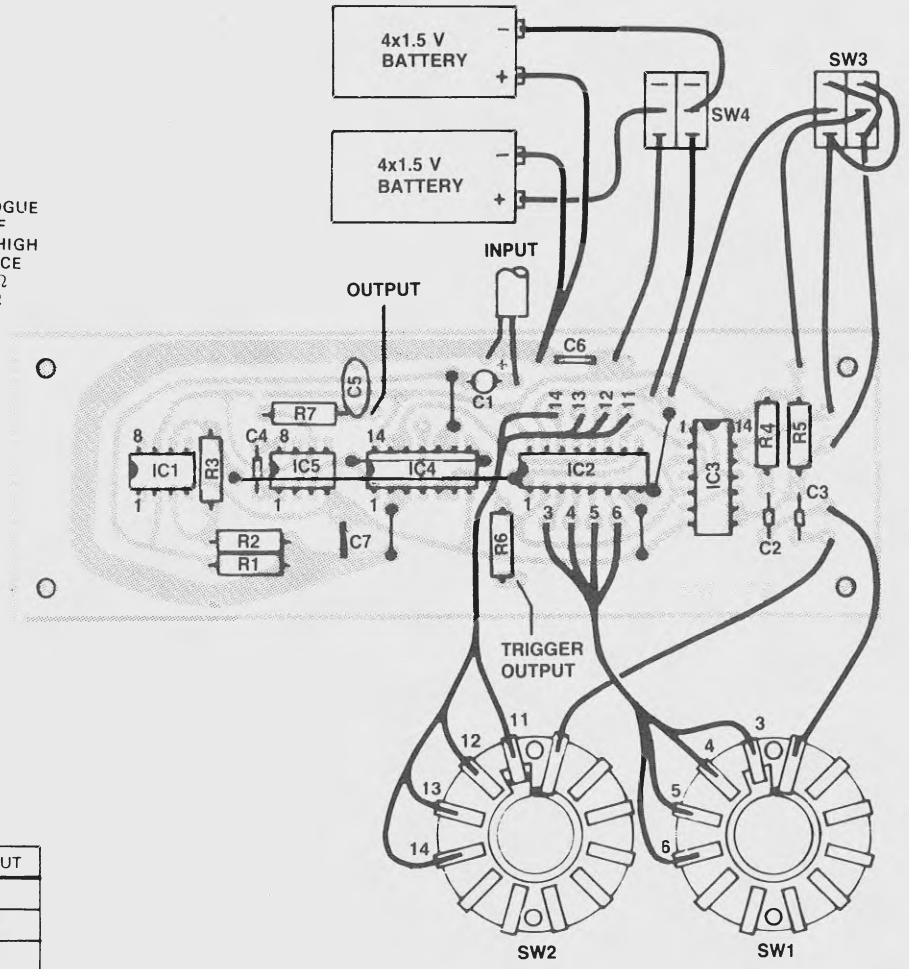


Fig. 2. Component overlay and interconnection diagram. Note that there are six links on the board, including two under IC4, which should be installed first.

HOW IT WORKS – ETI 124

The input signal is squared by comparator IC1 such that the output of the comparator will be high if the input is above +6 mV, and low if the input signal is below –6 mV. Resistors R2 and R3 provide the necessary positive feedback to cause the IC to act as a comparator. The output of the comparator is connected to both clock lines of IC2. If the enable line is high these counters (IC2) will toggle at the input frequency.

IC3/3 and IC3/4 form an RS flip flop where the output must be in either a high or a low state, that is the flip flop has only two stable states. If the output of IC3/3 is high IC2/1 is allowed to clock and, after the number of input pulses selected by SW1 have been counted, the output from SW1 goes low. This low is coupled to the flip flop by C2 toggling the flip flop, disabling IC2/1 and enabling IC3/2. After the number of cycles, as selected by SW2, have been counted the flip flop is again toggled. IC3/1 and IC3/2 are used to square up the pulses generated by C2 and C3 respectively.

The input signal is also coupled to the output buffer, IC5, by the analogue switch IC4/1. When this switch is closed (control signal high) the output of the buffer will be the same as the input. When switch IC4/1 is open IC4/2 will be closed and the output will be held at zero. Since these switches are controlled by the flip flop the output will be the required tone burst.

A trigger output is taken from the flip flop to synchronize an oscilloscope if required. A second output is also available from pins 4/11 of IC4 which is the reverse of the main output.

Switch SW3 forces the flip flop into either of its two possible states thus allowing continuous tone or no output to be selected as required. In the centre position the normal tone burst is obtained.

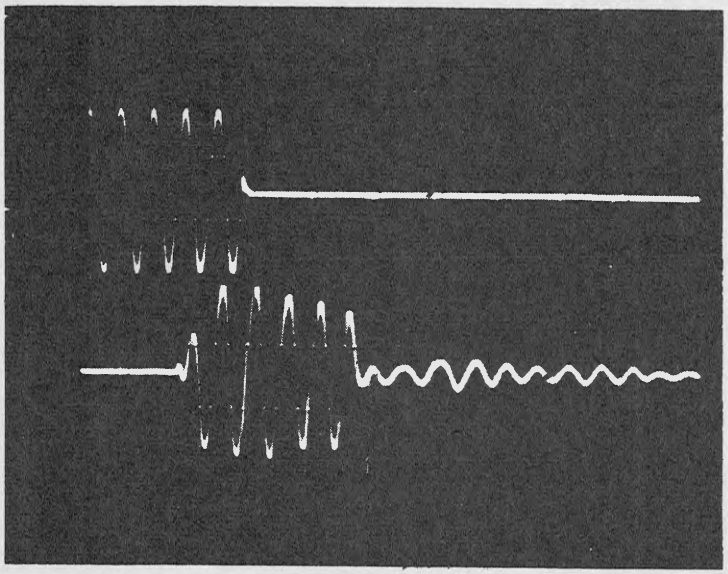


Fig.5 (a) Top trace – the input tone burst of five cycles. (original design). (b) Bottom trace – the response of a low-cost speaker at 1 kHz. Note the reduced amplitude of the first half cycle and that ringing has added another cycle at the end of the burst. The room reflection can be seen on the trace after the burst.

obtain times that remain in the same ratio regardless of input frequency. We settled for the ability to select 2, 4, 8 and 16 cycles for the duration of either period, as this compromise greatly simplifies the circuitry. We still have the switch to select tone, tone burst or off, but the OFF LEVEL control has been deleted. The latter control may quite easily be added, however, as shown in Fig. 4. . The output dc level control and the starting-point phase change have also been deleted.

Since we only need half of a CMOS 4016 IC, to give the required output, the other half may be used to give an inverse output if required, that is, the reverse output is on when the other is off and vice versa. This output is not buffered or brought out to the front panel. If it is intended to load this output with less than 47 k it is recommended that a 4066 IC be used instead which will handle loads down to 10 k. For loads of lower impedance than this, a buffer such as is on the normal output should be used.

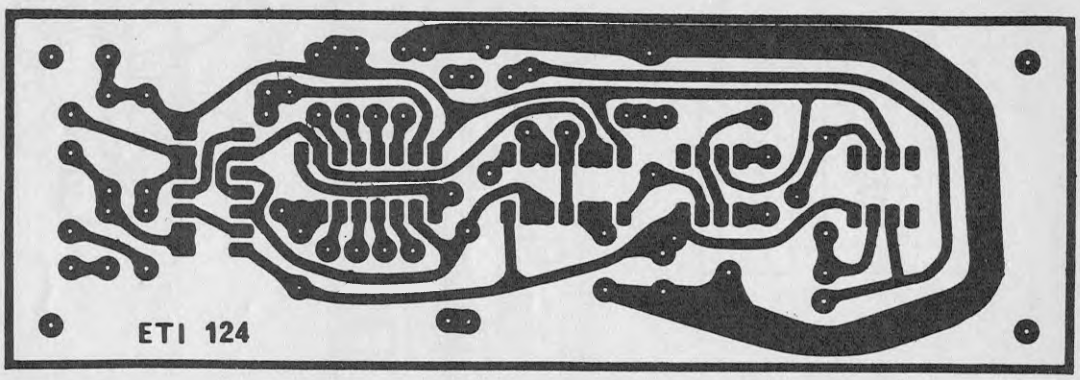


Fig.6. Printed circuit board for the Tone Burst Generator Full size. 142 x 47mm.

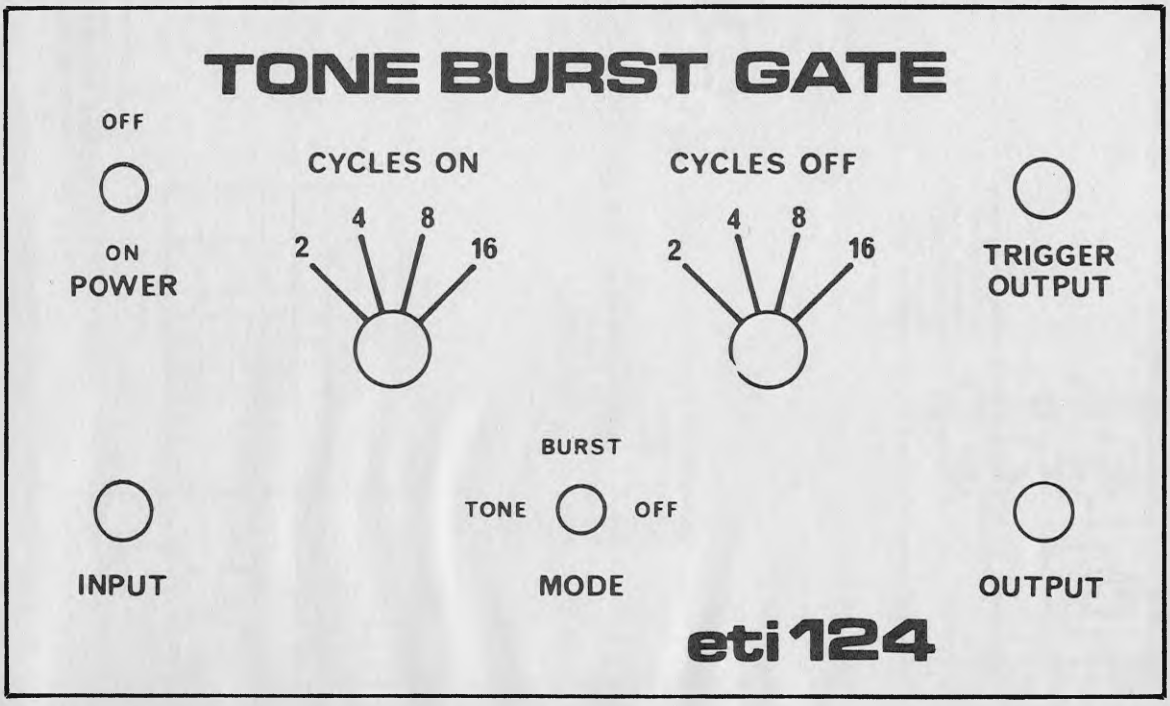


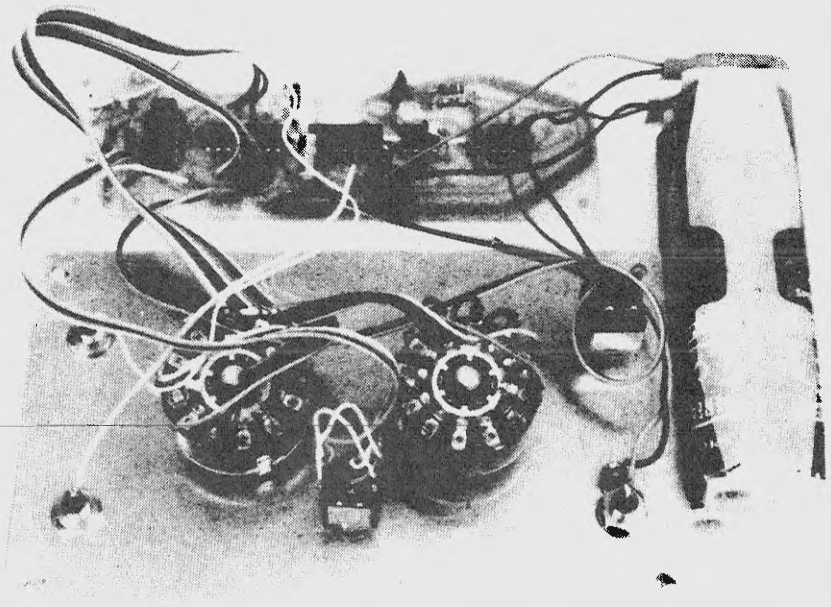
Fig.7. Front panel artwork.

CONSTRUCTION

As with any project construction is greatly simplified if a printed circuit board is used. However the layout of the unit is not critical and any other suitable method, such as Veroboard or Matrix board may be used if desired. We strongly recommend that sockets be used for the CMOS ICs, especially if a printed circuit board is not used, as these devices are quite easily damaged when soldering. The use of IC sockets also facilitates later servicing. Also remember that, unlike TTL, all unused inputs of CMOS must be connected to either the positive or negative supply rail.

The plastic box that we used measured 160 x 95 x 50 mm and is very convenient in that the printed circuit may be held in position by sliding it down behind two of the pillars to which the front panel is screwed. The front-panel overlay on the prototype was made from Scotchcal but, as the amount of lettering required is quite small, this may readily be done directly on the panel by hand or with Letraset.

Shielding of the internal wiring is not required providing that the unit is kept away from strong 50 Hz fields. If operation in the vicinity of strong fields cannot be avoided then the unit should be mounted in a diecast box.



How the unit is assembled.

USING THE UNIT

The testing of loudspeakers is very difficult indeed and much effort is still being spent to find test methods which will not only give an accurate understanding of the relative effectiveness of the design, but which will be easy to reproduce.

One of the main problems with speaker testing is that the speaker cannot easily be isolated from its environment. For example, reflections from the walls of a room modify the response, seen by a microphone, no matter where the microphone is placed in the room. If one could eliminate reflections then the situation would be improved considerably, and hence the use of anechoic (echo free) chambers for testing speakers. But such chambers are very expensive to build and consequently not readily accessible to the amateur.

A further problem is in assessing the transient power handling capability of the speaker. Speakers will handle far greater peak transient power than is indicated by their RMS power rating. This is a very important attribute of loudspeakers in handling musical transients. Any attempt to assess this with a sinewave signal may result in the destruction of the speaker due to thermal failure – apart from also being extremely noisy.

The use of a tone-burst generator minimizes both these problems. How this is achieved is better understood by examination of Fig.5. This shows on the upper trace a five cycle 1000 Hz burst that is fed to a loudspeaker. The second trace shows the same burst as picked up by a microphone in front of the speaker. We notice that the burst has been changed by the speaker and an examination of these changes can tell us a lot about the speaker. For example we notice that the first half cycle has not reached full amplitude and this indicates that the speaker would have some difficulty in reproducing high frequency transients. Next we notice that instead of five cycles there are now at least five and a half. This could mean one of two things. Either there is a speaker/room resonance or, the speaker itself is continuing to vibrate after the original excitation has ceased. Which is it? We can determine this by changing the position of the speaker to see if any change occurs in the shape of the burst, if not it is caused by the speaker itself, and if it does then it is a speaker/room resonance. A speaker that lengthens the burst unduly will sound muddy in that region. Of course the speaker must be examined over its whole range to gain a thorough assessment of performance.

It is of course possible to eliminate room reflections simply by performing the tests outside. However unless one lives in a very quiet area, background noise will introduce problems – and your neighbours are unlikely to appreciate the noise that you will generate.

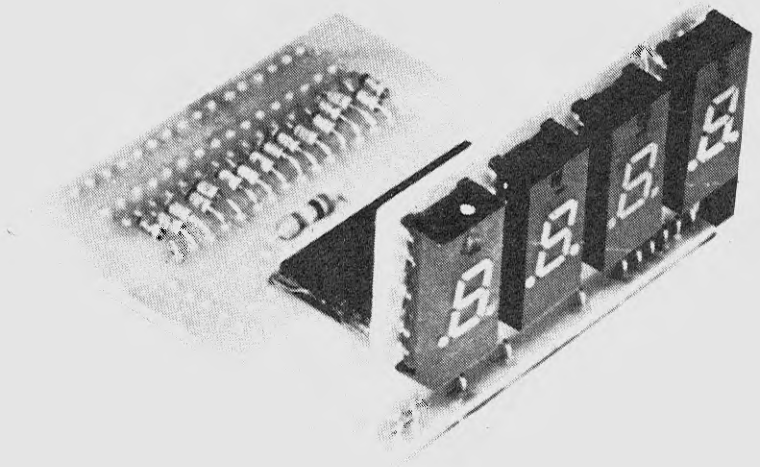
By varying the off period we can also select a ratio where the room reflection, the oscillation seen after the cessation of the burst, does not interfere with the first few cycles of the burst and the response versus frequency of the speaker may then be assessed from the amplitude of the first half cycles that are stable in amplitude. Thus it is possible to gain an appreciation of the frequency response, transient performance and quality in terms of ringing of a speaker by careful use of the tone-burst technique.

The transient power handling capability of a speaker may be assessed by selecting a fairly long off to on ratio for the burst and by feeding the burst to the speaker via a high-power amplifier. If for example an off to on ratio of 8:1 is used then the peak power will be eight times the average power. Thus the speaker may safely be driven to a peak level where a predetermined amount of distortion occurs. Take care that the amplifier is capable of providing the peak power required.

Of course a tone-burst generator may be used for a wide range of testing. We have mainly concentrated in this article on its application to the testing of loudspeakers.

The circuitry of the tone-burst generator may easily be modified for use as a 'silent switch' for A/B speaker testing.

Up/down presettable counter



THE THREE DIGIT display (ETI 533) we previously published has proved to be one of our most popular projects. We have used it in a number of projects and we know of several commercial companies using it in their own equipment.

Many people have asked us for a 4 digit version and we have been looking round at ICs available. We have chosen this Intersil device because we believe it offers the best versatility at the moment. Apart from being a 4-digit counter-latch-decoder driver needing no external components except the displays, it also is an up-down counter and can be preset to any number. In addition, it has a separate register which also can be set to any number and comparators which give outputs when the counter is equal to the register and when it is zero - all in one IC!

Construction

The unit is built on two small pc boards which are connected together with short links of tinned copper wire. Be careful to orientate the IC correctly as it is expensive!

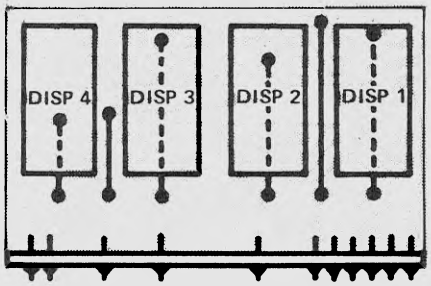
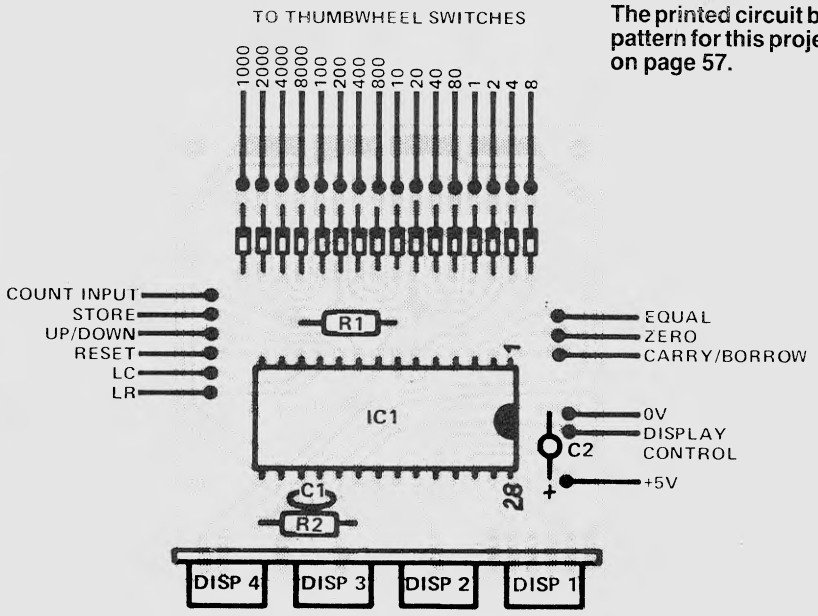


Fig. 1. The positioning of the displays and the links which must be installed before the displays.

Fig.2. The component overlay for the main board. The common connection from each of the thumbwheel switches goes to the track next to the other connections.

The preset system is designed to use a 4 digit BCD thumbwheel switch (closed = '1') but individual switches can be used if required. Input is in BCD, therefore the switches will have the weighted values 8, 4, 2 and 1. If the preset is not needed then the diodes can be left out. If a preset is needed, but always to a fixed number, links can be inserted to replace the "on" switches and the other diodes left out.



The printed circuit board pattern for this project is on page 57.

HOW TO USE IT

This section is normally How it Works but as it is only one IC there is not much to be said!

Count Input - Pin 8

The counter is incremented or decremented on the leading edge of this input. A schmitt trigger is provided with a 500 mV hysteresis on a 2V trigger point. For high speed operation, or operation from a digital output, delete R2 and C1 and short out R1. Maximum frequency of operation is about 2 MHz.

Up-Down - Pin 10

If this pin is left open or taken to +5V the counter will be incremented by the count input. If it is taken to 0V the counter will be decremented by the count input.

Reset - Pin 14

If this pin is left open or taken to +5V the counter is free to be incremented or decremented. If it is taken to 0V the counters will be reset to zero and held there until reset is taken high again.

Store - Pin 9

If this input is left open or taken to +5V the latches are "closed" and the information which was in the counters at the time the store input went high will be remembered, decoded and displayed. The counters can be reset, incremented or decremented without affecting the display.

If it is taken to 0V the counter contents will continuously be displayed for as long as this input is at 0V. Any change in the counter contents will be shown on the display.

Load Counter - Pin 12

This is a 3 level input. If it is left open the counter works normally. If it is taken to +5V the counter is loaded with the BCD data which is set on the thumbwheel switches. If the latch is open, this number will also be displayed. If this input is taken to 0V the BCD I/O pins become high impedance. If a 3 level input is to be controlled by other logic outputs they must be tristate devices.

SPECIFICATION

Number of digits	4
Readout	LED
Maximum frequency	2MHz
Input impedance	100k
Output drive	1 TTL load
Supply voltage	4.5 – 5.5V
Supply current	
low power mode	500μA
all eights	100mA

PARTS LIST

Resistors all ½W, 5%
R1 . . . . . 100k
R2 . . . . . 1M

Capacitors
C1. . . . . 33n polyester
C2. . . . . 1μ0 35V tantalum

Semiconductors
IC1 . . . . . ICM 7217A
D1–D16 . . 1N914
DISPLAYS. DL704

Miscellaneous
PC boards ETI 591A, ETI 591B

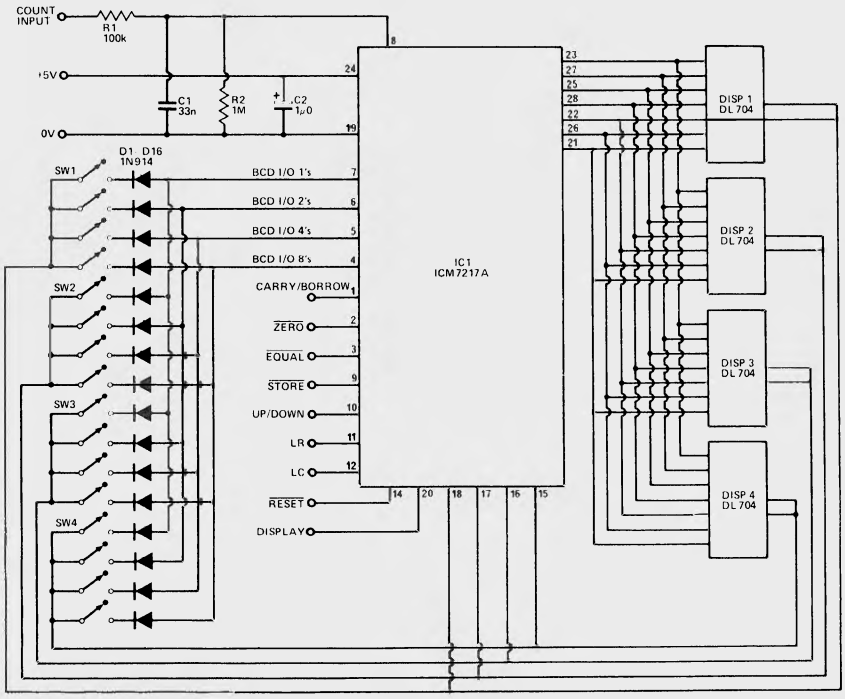


Fig. 3. The circuit diagram for the counter board.

Load Register - Pin 11

This is also a 3 level input. If it is left open the counter works normally. If it is taken to +5V the register is loaded with the BCD data. If taken to 0V the circuit goes to a low power state with the multiplexing oscillator stopped, the display off and the BCD I/O pins in a high impedance state. The operation of the counter is unaffected except that there is no display.

Display Control - Pin 20

This is also a 3 level input. If it is left open, leading edge blanking occurs. If all digits are zero then all are blanked. If it is connected to +5V the display is completely blanked irrespective of the value. If taken to 0V all digits are ON irrespective of value.

Scan - Pin 13

The internal multiplexing frequency is nominally 10 kHz giving a digit repetition rate of 2.5 kHz. With a 20 pF capacitor from this point to 0V the frequency drops to 5 kHz and with 90 pF it is about 1 kHz.

BCD I/O - Pin 4-7

This is a multiplexed data port, normally an output which can drive 1 TTL load. It becomes an input when either LC or LR is at +5V. Pin 7 is the least significant bit.

Digit Drives - Pins 15-18

These are used both to drive the LEDs and to provide data indicating which digit is being presented at the BCD I/O port. Pin 18 is the least significant digit.

Zero - Pin 2

If the value of the counter is zero this output will be at 0V.

Equal - Pin 3

If the value of the counter is equal to the value of the register this output will be at 0V.

Carry/Borrow - Pin 1

When the counter goes from 9999 to 0000 or from 0000 to 9999 a 500 ns positive pulse occurs on this output. This is connected to the count input of a second unit when an eight digit display is needed.

Field strength/power meter

Versatile unit indicates transmitter tune-up.

TWO PIECES OF equipment which are almost essential to the CB'er, novice, or amateur alike, are a field strength meter and a power meter. This design combines the two in a simple easy to construct circuit comparable to equipment many times its cost.

Measurement of field strength is useful for antenna tuning, especially where an antenna tuning unit is used, or for checking the radiation pattern of a directional antenna. If the meter is left in a fixed position well away from but at the same height as the antenna, and the antenna rotated, a circular plot of the antenna radiation pattern can be drawn up. When tuning an antenna the meter should be placed in a convenient position where it can be seen and the tuning adjusted for maximum reading.

The power meter is used to tune the output of a transmitter, or can be left in the transmission line as a monitor of power output. The reading on the meter will only be accurate if the antenna has low VSWR. For accurate power measurement, and for transmitter tuning, a dummy load should be connected to one of the power sockets. If only the 20 watt range is used a small CB dummy load is suitable, a larger load of course being necessary for the 200 watt range. Table 1 gives the power calibration for both ranges for a 50 μA meter or the scale can be cut from page 58.

Construction

Figure 2 shows the wiring layout for the unit. This layout should be strictly adhered to, otherwise performance may

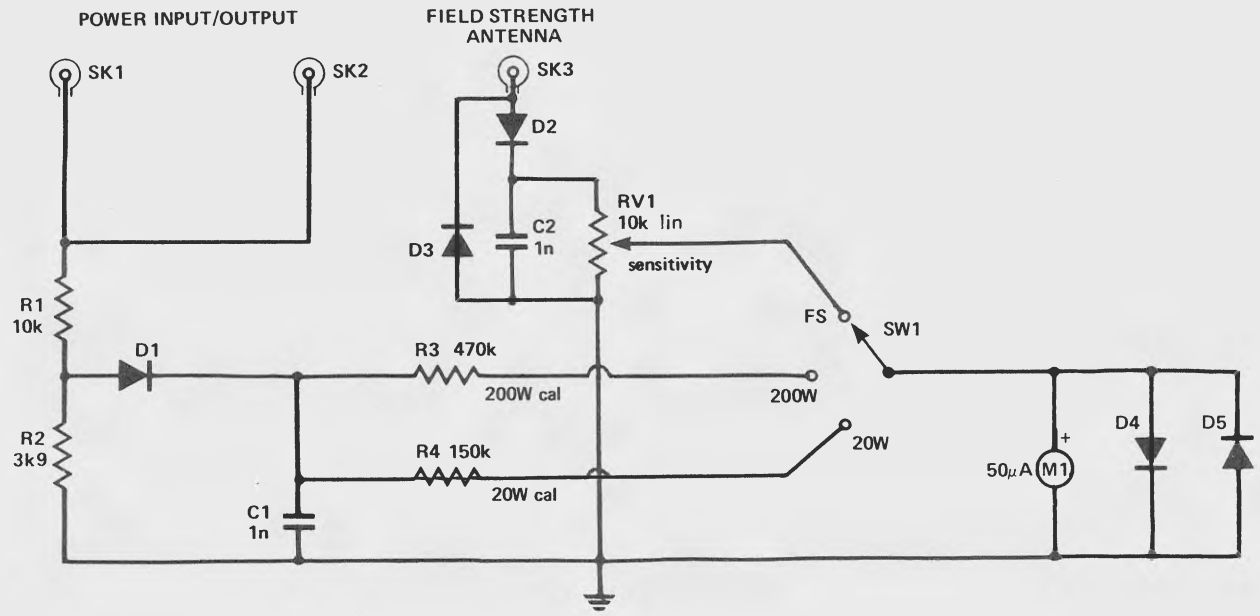


Fig. 1. Circuit of the Field Strength/Power meter.

be affected. All leads, especially the earth leads, should be kept short.

Components for the power meter are assembled on a small piece of matrix board, which is then held in place by the meter terminal screws.

We used a Horwood instrument case type 32/2/D, available from Radio Dispatch Service or Dick Smith Electronics, which measures only 75 mm x 100 mm x 50 mm deep. A C&K type 7211 toggle switch is used for the function switch, although any suitable switch which will fit into the constraints of the box will do equally as well.

A whip antenna for the field strength meter was made by soldering a length of brazing rod into a PL259 UHF plug and filling the space with Araldite. The sensitivity of the meter will increase with the length of the antenna.

Meter scale and front panel artwork are on page 58.

How It Works – ETI 719

Let's look at the field strength meter first.

Some signal is picked up by the whip antenna and is detected by D2 and C2. The capacitor, C2, charges to a voltage proportional to the field strength of the signal. A return path for the charging of C2 is provided by D3. The sensitivity control, RV1, varies the current fed from C2 to the meter, via the function switch SW1. The meter will give a reading proportional to the field strength of the signal. The diodes D4 and D5 provide meter overload protection by conducting when the voltage across the meter terminals exceeds about 0.7 volts.

Power Meter

The power meter is similar in operation to the field strength meter, but instead of taking the signal from the antenna it measures the voltage on a 50 ohm transmission line. R1 and R2 form a voltage divider to reduce the voltage to be measured and to provide isolation between the measuring circuit and the transmission line. The RF signal is then detected by D1 and C1, the voltage across the capacitor being proportional to the voltage on the transmission line. The power in the line is then proportional to the square of this voltage ($P = V^2/R$ and $R = 50\Omega$). This voltage is measured by a dual range peak reading voltmeter formed by R3, R4 and M1. The meter is calibrated for 20 watts and can also be used for the 200 watt range. The voltmeter gives an accurate reading for both carrier power (AM), and peak envelope power (PEP).

METER CALIBRATION

Power	Scale		
0.5	8	9	33.5
1	11	10	35
2	16	11	37
3	19	12	38.5
4	22	14	42
5	25	16	44.5
6	27.5	18	47.5
7	29.5	20	50
8	31.5		

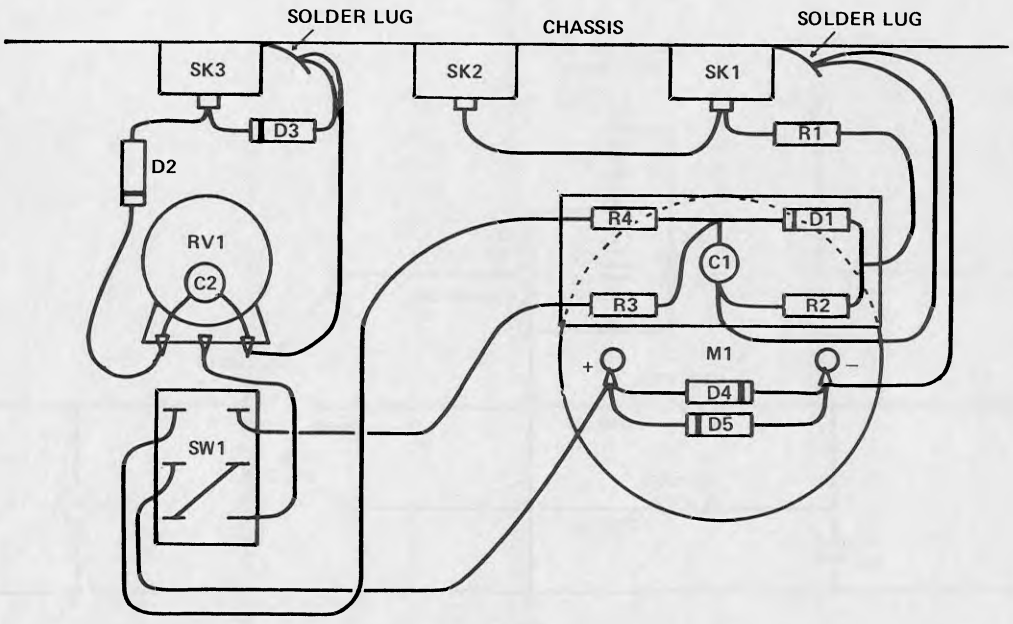
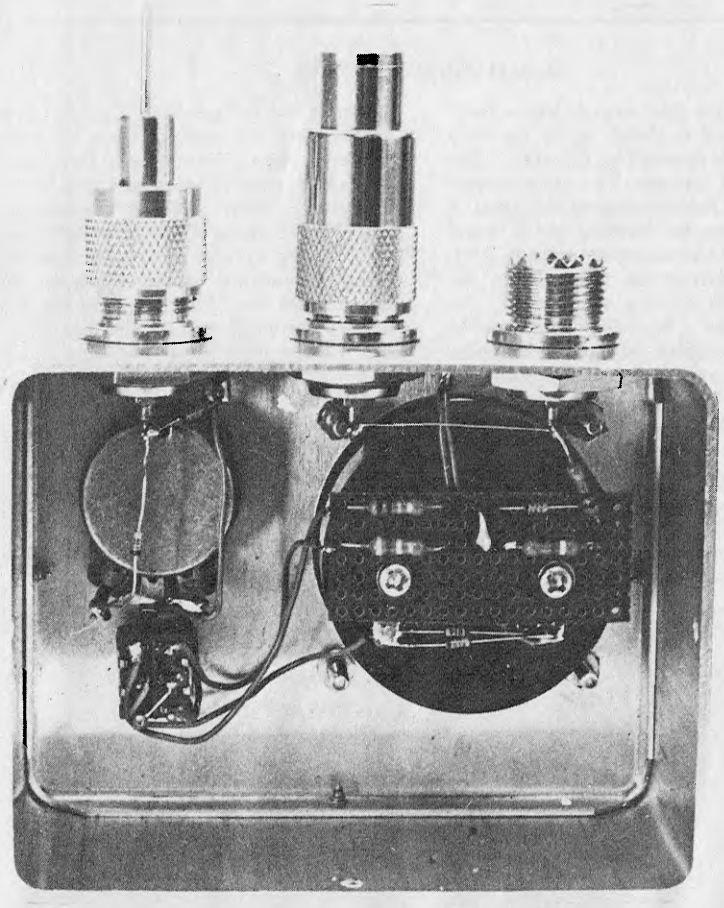


Fig. 2. Wiring layout of the unit. Matrix board is used to mount the components for the power meter.



The completed meter. All leads, especially the earth leads, should be kept as short as possible.

PARTS LIST – ETI 719

Resistors all ¼W 5% except R1
R1 . . . . . .10k 5% ½W
R2 . . . . . .3k9
R3 . . . . . .470k
R4 . . . . . .150k

Potentiometer
RV1 . . . . . .10k lin.pot.

Capacitors
C1, 2 . . . . . .1n ceramic

Diodes
D1 – D5 . . . . . .1N914

Miscellaneous
SW1. . . . . .C&K 7211 (see text)
SK1 – SK3 . . . .S0239 UHF socket
M1 . . . . . .50 μa 50 mm meter
Horwood instrument box 34/2/D (see text)

Accessories
50ohm CB load
PL259 UHF
C2. . . . . .1000u 25VW electro
SW1. . . . . .SPDT min. toggle

Linear-scale capacitance meter

If you want to find out what values those odd capacitors are, then here's the instrument for you.

ONE OF THE handiest instruments for an electronics hobbyist, or an electronics workshop, is a capacitance meter. Every multimeter has a resistance scale – and it gets used quite often. But there is often a requirement for measuring capacitance, and few multimeters have a capacitance range.

For example, measuring the value of a variable capacitor used to temporarily 'trim' a filter or oscillator that is to be replaced by a set of fixed capacitors. Or a bagful of 'bargain' unmarked capacitors may have been obtained or the color code or numeral code has disappeared and the value of a component needs to be determined.

Once you have a capacitance meter, you suddenly find uses for it!

This capacitance meter provides a linear scale readout of the value of unknown capacitors generally to within 5% or as good as 2% depending on the accuracy of the meter used.

Range

The meter will measure capacitance values down to 5 pF and up to 1 μF. Scale divisions on the model shown were at 2.5% intervals.

Five ranges are provided: 100 pF, 1 nF, 10 nF, 100 nF and 1 μF.

Different ranges can be provided by selecting different values for the range resistors R7 to R11. For example, five ranges from 47 pF to 0.47 μF could be included by changing R7 to 470 ohms, R8 to 4.7k etc. The meter scale would have to be hand-calibrated in this case.

Construction

The construction is quite straightforward. The majority of the small components are mounted on the printed circuit board. The range resistors are mounted on the switch lugs as illustrated in the photographs.

All the range resistors, R7 to R11, and R12 are high tolerance 1% or 2% resistors accurately measured to be within the tolerance required. If only 5% or 10% accuracy of capacitance value is required then standard 5% or 10% tolerance resistors may be used, obviating the need for selecting them, or buying the expensive high tolerance types.

SPECIFICATION – ETI 136

Capacitance ranges	100 pF, 1 nF, 10 nF, 100 nF, 1 μF.
Accuracy	5% or better (2% possible with component selection)
Calibration	by internal calibration capacitor
Power requirements	240 V AC or 2 x 9V No. 916 batteries

The printed circuit board, meter, range switch, potentiometers, pilot light measurement terminals and on/off switch are all mounted on the front panel as illustrated.

The power supply is mounted on the back panel, as is the mains/battery switch. The batteries (if used) may be mounted inside the case. Overall case size is 180 mm wide by 95 mm deep by 128 mm high.

A small tagstrip is used to terminate the mains input and transformer leads and the rectifier components. Both the back panel and the front panel should be connected to the mains earth which is terminated on the tagstrip, the strip's earth tag being secured under one of the transformer mounting bolts.

The calibration capacitor is a high tolerance (2% or better) polystyrene or, better still a silver mica type. This component is mounted from the appropriate switch lug to a suitable ground lug mounted on the front panel.

The printed circuit board has PC stakes (or pins) soldered in all the positions marked on the component overlay.

Two of these (marked E and Cx on the PC artwork) are used to mount the PCB directly on the back of the "Cx" terminals, as illustrated in the photographs. This avoids increasing the circuit stray capacitance.

Little difficulty should be experienced if the component overlay is followed and the photographs are referred to during construction.

Note that alternative panel layout is possible if a standard type of panel meter is used rather than the edgewise meter shown in the photographs.

The front panel was hand-lettered with Letraset on the prototype. A Scotchcal type front panel could also be prepared if desired.

The CAL. potentiometer is a screwdriver-adjust type and was mounted with a fixing collet. Knob-twiddlers can cause havoc.

Using the Meter

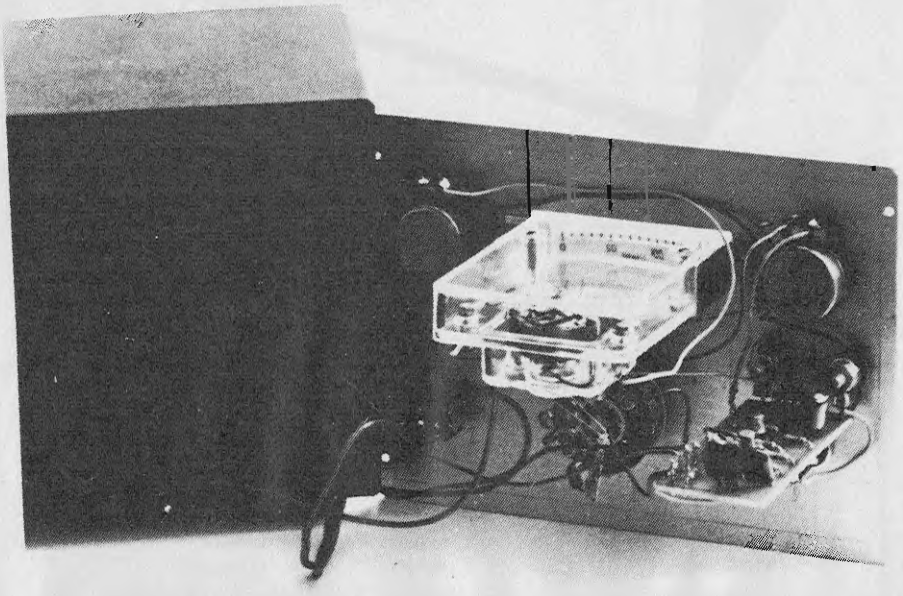
Once the instrument has been tested and confirmed to be in working order, switch the range switch to the 100 pF position and turn the SET ZERO control so that the meter reads zero with no capacitor connected to the Cx terminals. Then switch to the CAL. position and adjust the CAL. potentiometer so that the meter reads full scale.

Now you are set to measure all those 'unknown' capacitors.

Any devices used to grip capacitors being measured, and plugged into the Cx terminals, will add stray capacitance and this will need to be compensated for by readjusting the zero set control.

Continued on page 94.

Note: Suitable edge meters are often obtainable from surplus component stores. The particular meters are 0–1 mA movements calibrated 0–5 ounces. The scale is easily removed and reversed to provide a blank scale which can be hand-calibrated (use a reg. voltage supply, a good pot and a mirror scale or digital meter to set the current points). This is best done with the meter mounted on the panel. Excellent accuracy can be obtained.



PARTS LIST – ETI 136

Resistors

R1	560k, ¼W
R2	470 ohm. ¼W
R3, 6, 13	1k5. ¼W
R4	120 ohm
R5	10k, ¼W
R7	1k, ½W. 2%
R8	10k, " " either use 2% tol.
R9	100k " " resistors or selected 5% or 10% tol. see text.
R10, 12	1M " "
R11	10M " "
RV1	10k/A panel mounted, screwdriver adjusted
RV2	500 ohm/A pot.

Capacitors

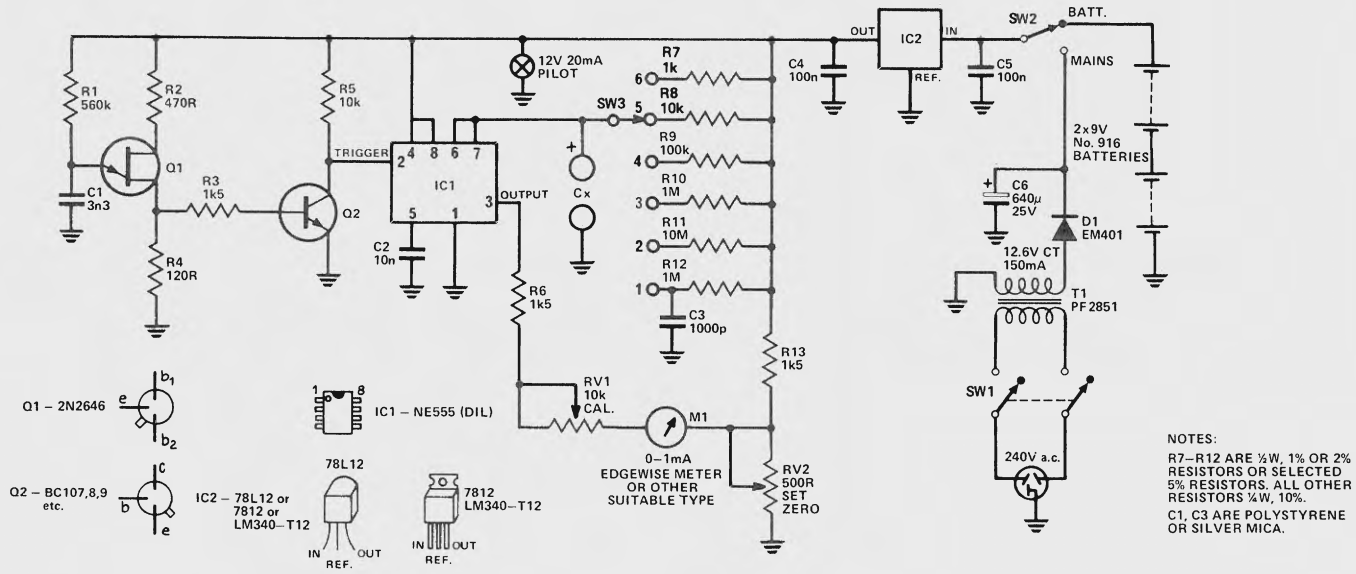
C1	3n3, Philips polystyrene or silver mica
C2	10nF greencap or ceramic
C3	1nF Philips polystyrene (selected, 2%) or silver mica, 2%
C4	100nF greencap
C5	100nF greencap
C6	640 uF, 25V electrolytic

Semiconductors

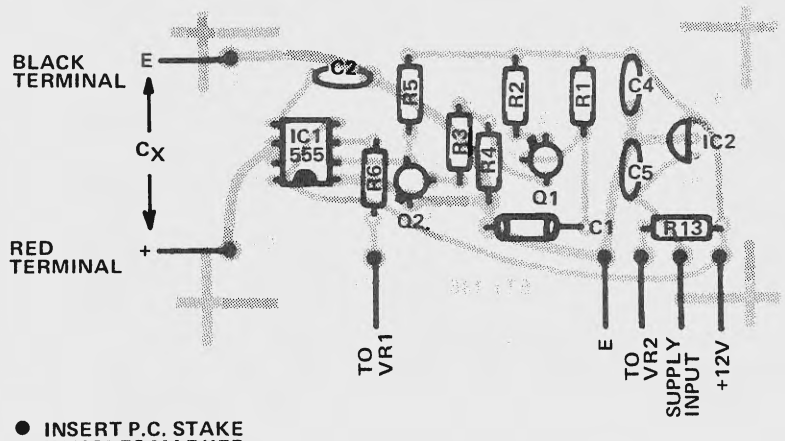
D1	EM401 or similar
S1	DPST or DPDT, 250 V AC rated min. toggle switch
S2	SPDT or ½-DPDT min, toggle switch
S3	single pole, six-position OAK switch
Q1	2N2646
Q2	BC107 or BC108, BC109 or equivalent
IC1	LM555 or NE555 timer IC.
IC2	78L12 (preferred) or 7812 or LM340-T12

Miscellaneous

T1	PF2851 or M2851, 12.6 V C.T. @ 150 mA
Pilot	12 V, 20 mA bayonet lamp and holder.
Case	Instrument case, Australian Transistor Co. model 754 or similar
M1	O-1 mA meter, see text
Sundries	pk screws, wire, batteries, nuts, bolts, tagstrip, etc.



NOTES:
R7–R12 ARE ½W, 1% OR 2% RESISTORS OR SELECTED 5% RESISTORS. ALL OTHER RESISTORS ¼W, 10%.
C1, C3 ARE POLYSTYRENE OR SILVER MICA.



R7-R12 and C3 are mounted on the rear of the range switch. R7 to R12 and the pilot lamp connect to the point marked '+12V' on the overlay. The common connection to switch SW3 should be taken from the point marked 'red terminal' on the overlay.

The printed circuit board pattern for this project is reproduced on page 56.

● INSERT P.C. STAKE IN HOLES MARKED THUS.

HOW IT WORKS – ETI 136

A unijunction transistor, Q1, is connected as a relaxation oscillator with a frequency determined by R1-C1. The frequency of oscillation in this instance is about 1 kHz.

Pulses of about 1 µs duration are produced across R4 each time the UJT "fires". The resistance between b2 and b1 of the UJT reduces to a low value each time the emitter conducts. Much of the charge stored in C1 is "dumped" across R4 for the short duration that the c-b1 junction of Q1 conducts.

The narrow pulses across R4 drive the base of Q2 via R3, which serves as a base-current limiting resistor. The pulses cause Q2 to conduct for the same duration, that is, about 1 µs, and negative-going pulses from the collector of Q2 drive the "TRIGGER" input of the 555 timer, IC1. This is connected to operate as a monostable in this circuit.

When IC1 receives a trigger pulse at pin 2, the flip-flop is set, releasing the short circuit across Cx and driving the output, pin 3, high. The voltage across the capacitor then increases exponentially for a period that depends on the value of the unknown capacitance Cx. The period is determined according to the formula:

$$t = 1.1\ RrCx$$

At the end of the period, the comparator resets the flip-flop which in turn discharges the unknown capacitor, Cx, and drives the output to its low state.

This cycle is repeated each time a negative-going trigger pulse appears at pin 2 of IC1.

Thus as the range resistor value (Rr) is fixed, the ON/OFF ratio of the output voltage will be determined by the value of Cx. The ON/OFF ratio is independent of the relaxation oscillator frequency and trigger pulse duration.

The current measured through the 'load' resistor on the output (R6) of IC1 will thus be directly proportional to the value of the unknown capacitor Cx.

The meter, M1, measures the current through R6, the meter inertia 'averaging' the current.

As the voltage at the output pin swings between about 2/3 Vcc and less than 1/3 Vcc in its 'high' and 'low' states respectively the DC offset is compensated for by returning the 'load' current through an offset voltage developed across VR2 via R13 from the supply rail.

Zero-setting is accomplished by making VR2 variable. A calibration control is provided by making a portion of the 'load' resistance variable – VR1 here.

However, this will only have to be done on the 100 pF and 1000 pF ranges as the added capacitance will be negligible on the higher ranges.

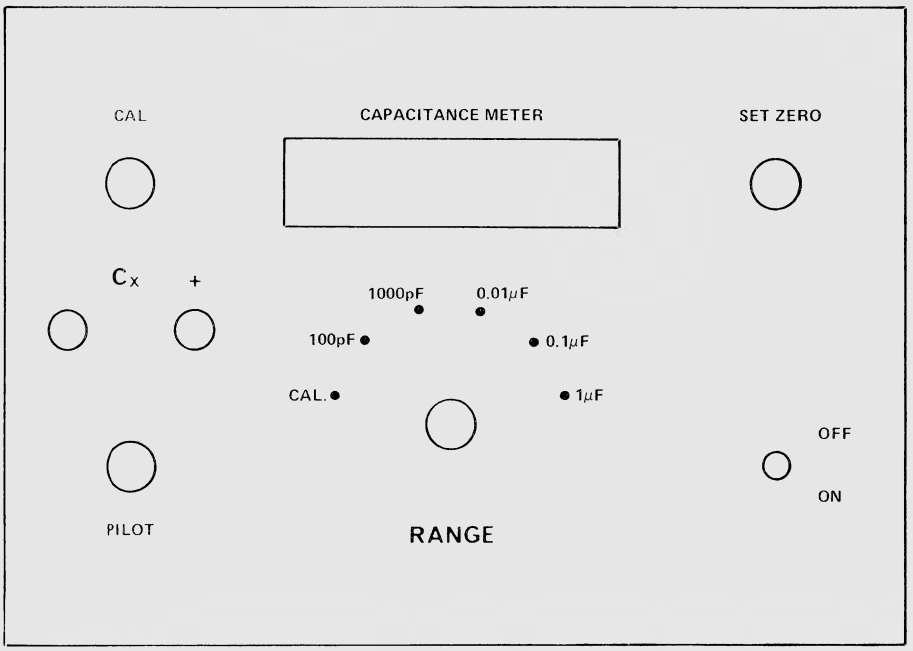
Meters

An edgewise-mounted panel meter was used in the prototype for several reasons. Firstly, we had one! Secondly, a scale nearly 50 cm long allowed us to calibrate the meter at very close intervals – 2.5% here, and still give accurate readout. Thirdly, the edge meter used little panel space, giving it a clean, uncluttered appearance.

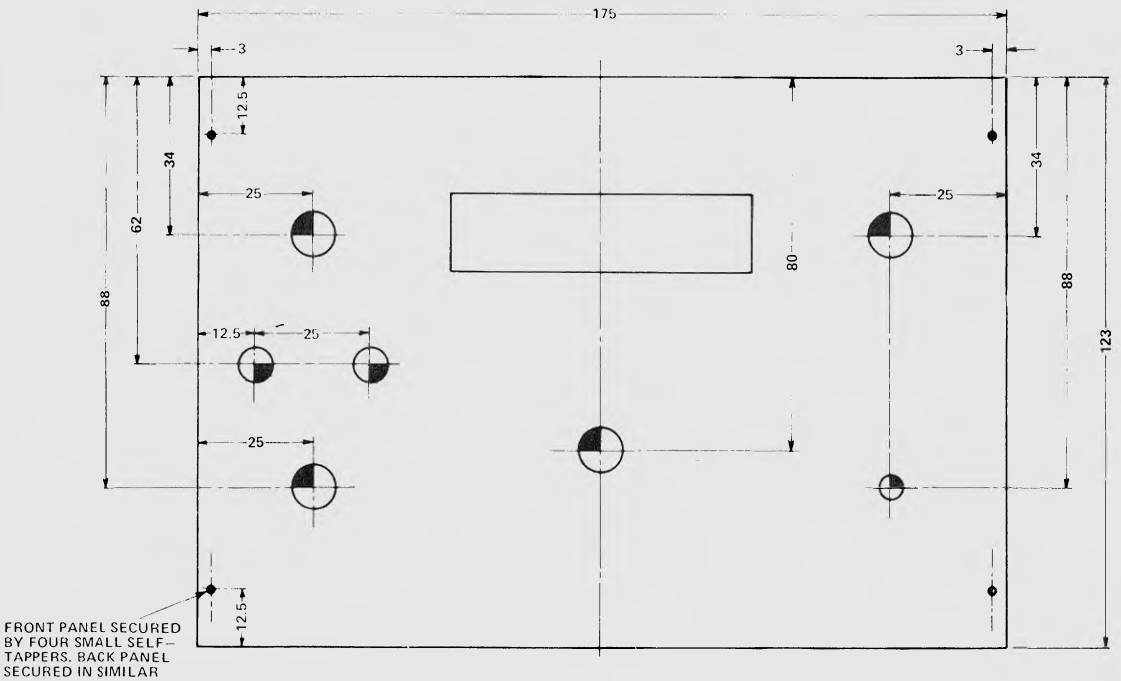
A 0–1 mA meter was used as it has a convenient scale. If you use a range with full-scale values of 47 pF to 0.47 μF a 500 μA FSD meter will have to be used.

The zero-set potentiometer, VR2, provides a small voltage offset as the output, pin 3, or IC1 does not go to zero volts and it also compensates for the effect of the small stray capacitance in the construction.

A calibration position is provided on the range switch for the sake of convenience. The original model did not have this refinement but we soon added it when we found out how useful it was! it also helps to maintain accuracy as a 'standard' capacitor does not have to be kept external to the instrument for this purpose – we kept losing ours until we put it in the circuit!



PANEL LETTERING



NOTES:

- 4 HOLES, 10mm DIA.
- 1 HOLE, 6mm DIA.
- 2 HOLES, 8mm DIA.
- 4 HOLES, 2mm DIA.

ALL DIMENSIONS ARE IN MILLIMETERS.

PROTOTYPE PANEL LAYOUT

Crosshatch generator

New oscillator scheme allows simplified set-up procedure.

THE COLOUR television picture is created in the receiver picture tube by three separate electron guns - one each for red, green and blue. As these guns cannot be in the same physical position they need to be converged into one spot on the screen.

The process of converging at the centre of the screen is called static convergence and is performed by magnets on the yoke assembly.

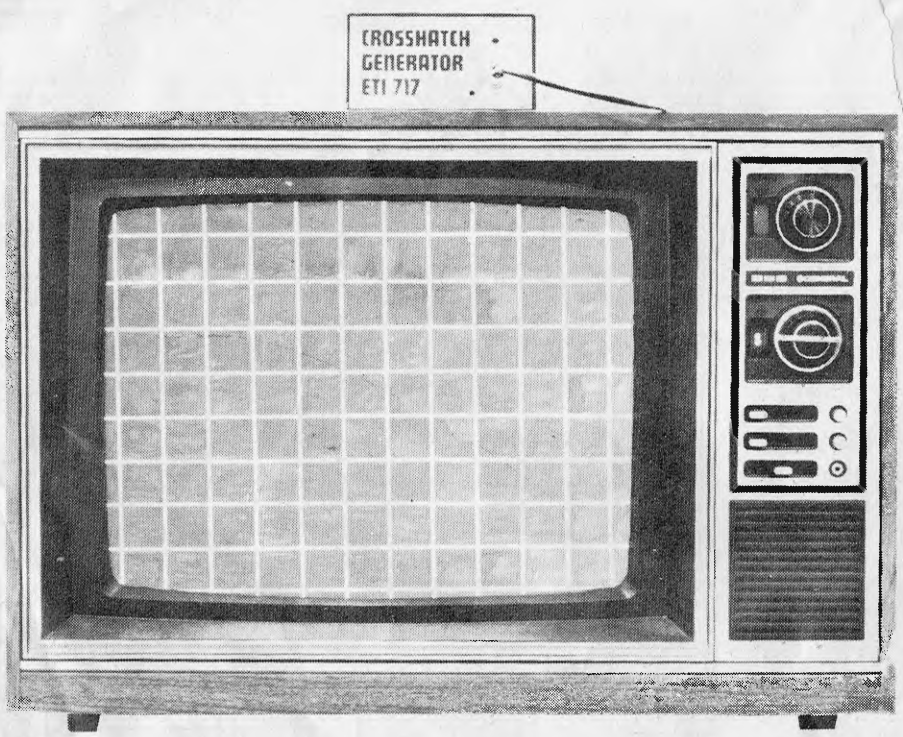
However, the screen of the picture tube is not everywhere coincident with the deflection plane and this causes errors when the beam is deflected away from centre. These deflection errors are corrected electronically by 12 or more controls and the process is known as dynamic convergence.

An important part of the process is the use of a crosshatch generator to provide horizontal and vertical lines on the screen. Using the generator, the convergence errors are immediately apparent and the controls on the set are usually labelled with the effect each has on a crosshatch pattern.

In addition to setting up convergence the generator pattern may also be used to set up horizontal and vertical linearity and to orientate the deflection yoke coils on both black and white and colour sets.

Most of the inexpensive pattern generators, which are currently available, produce a video waveform, which must be injected into the correct place in the TV, and require a synchronizing signal from the TV set. Such generators are thus fiddly things to use.

Text continued on page 98.



The new ETI 717 crosshatch generator replaces the earlier ETI 704 and is considerably easier to set up.

SPECIFICATION – ETI 717

Line spacing	
Horizontal	every 16 lines
Vertical	every 4 μs
Number of Lines normally visable	
Horizontal	9
Vertical	12
Output impedance	75ohm
Power consumption	16mA @ 9V
Battery life (Type 216)	10–12 hours

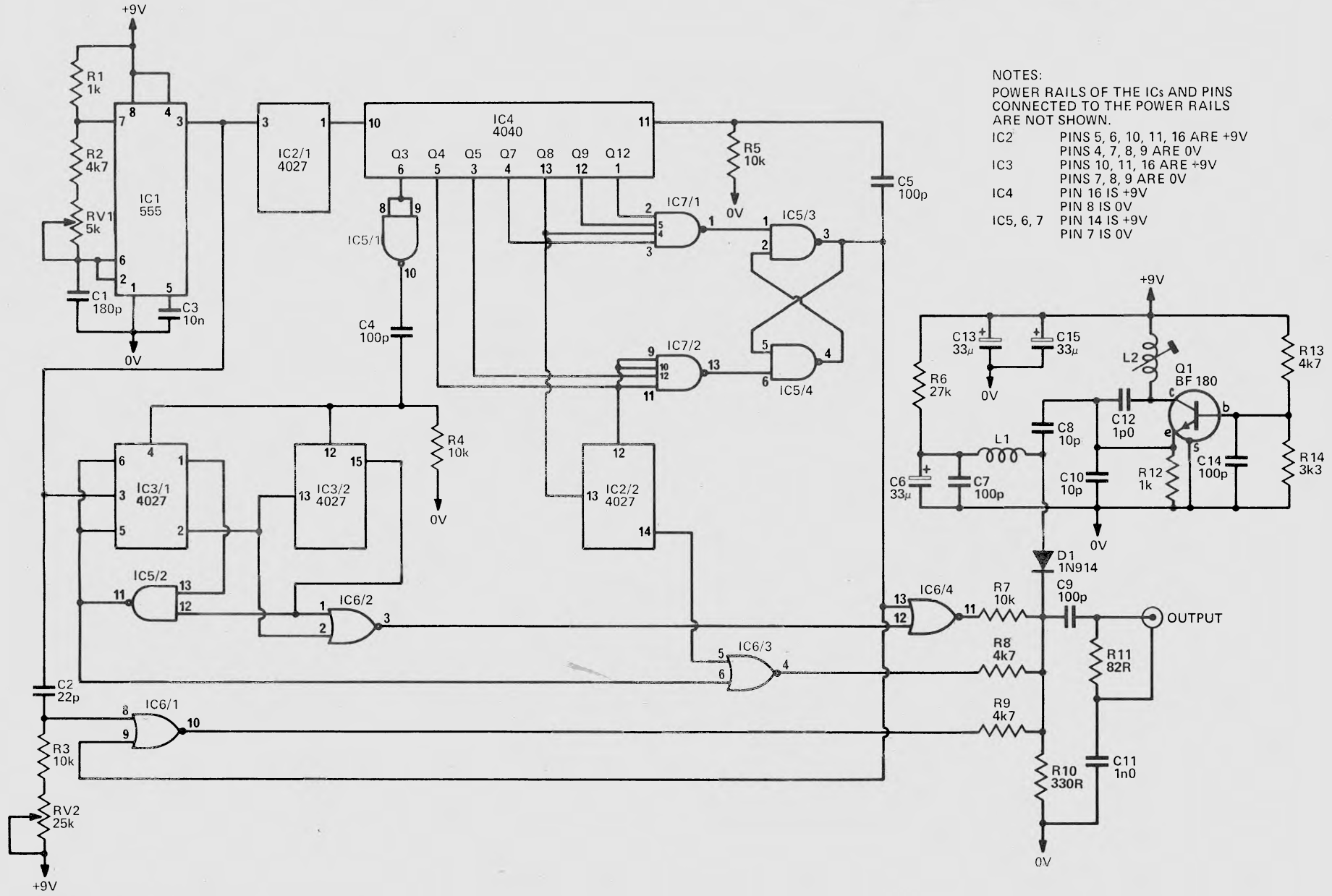


Fig. 1. The circuit diagram of the crosshatch generator.

HOW IT WORKS – ETI 717

A TV picture is made up of a series of horizontal lines equally spaced down the screen with the information transmitted in a serial form along with the necessary synchronization pulses. In Australia there are 625 lines in each complete picture but these are transmitted as two "frames" each of 312½ lines with the second frame interlaced between the first giving a total of 625 lines. This is to reduce flicker of the picture which would otherwise occur.

To simplify our circuit and prevent a double horizontal line we have used 624 lines which eliminates the interlacing. The TV set automatically accepts this change.

To synchronize the TV set we need a 192μs wide pulse every frame (20ms) and a 4μs wide pulse every line (64μs). All pulses, including the information, are derived from a single 249.6 kHz oscillator IC1. This is divided by 2 in IC2/1 and then by 2496 by IC4 giving an output of 50 Hz. This IC is a 12 stage ripple counter which, while normally dividing by 4096, can be forced to divide by 2496 by decoding (IC7) the outputs from the 7th, 8th, 9th and 12th stages and resetting IC4 back to zero. The output of IC7 toggles the RS flip flop IC5/3, IC5/4 which resets IC4 via C5. This flip flop is reset by the decoded output from the 4th and 5th stages of IC4. This occurs 192μs later; thus the output from IC5/3 is the frame sync. pulse.

To generate the line sync pulse the output from the 3rd stage of IC4 (15,600 Hz) is used to reset both halves of the dual JK flip flop IC3. This IC is then toggled by the 249.6 kHz clock until, after three pulses, both "Q" outputs are "1" when IC5/2 detects this and disables IC3/1. IC6/2 decodes the second of these clock periods and this becomes the line sync pulse. These pulses are combined in IC6/4 to give a combined sync pulse.

The 249.6 kHz is differentiated by C2/R3 and after being squared up by IC6/1 is used to generate 16 white spots on each line which results in vertical lines. These pulses are deleted during the frame sync period to prevent interference to synchronization. Due to variations in the CMOS a trim potentiometer is provided to give equal width to the vertical and horizontal lines.

The horizontal line is generated by IC2/2 (JK flip flop) and this IC is toggled by the 8th output (487.5 Hz) of IC4 and is reset by the output of the 4th stage (64μs later). This gives a single white line every 16 lines. To prevent this line interfering with the line sync pulse the output of IC2/2 is combined with that of IC5/2 which is high for a period 4μs before the line sync pulse to 4μs after the pulse. This gives a short black region on both ends of the line (normally off the screen). The outputs of IC6/1, IC6/2 and IC6/3 are combined by R7-R10 to give a composite video signal. Note that the video information gives positive pulses while the syncronization pulses are negative.

The VHF oscillator, Q1, is mixed with this signal and the resulting modulated signal can be tuned in by the TV set. Adjustment of the frequency by the tuning slug allows operation on any desired channel from 7 to 10.

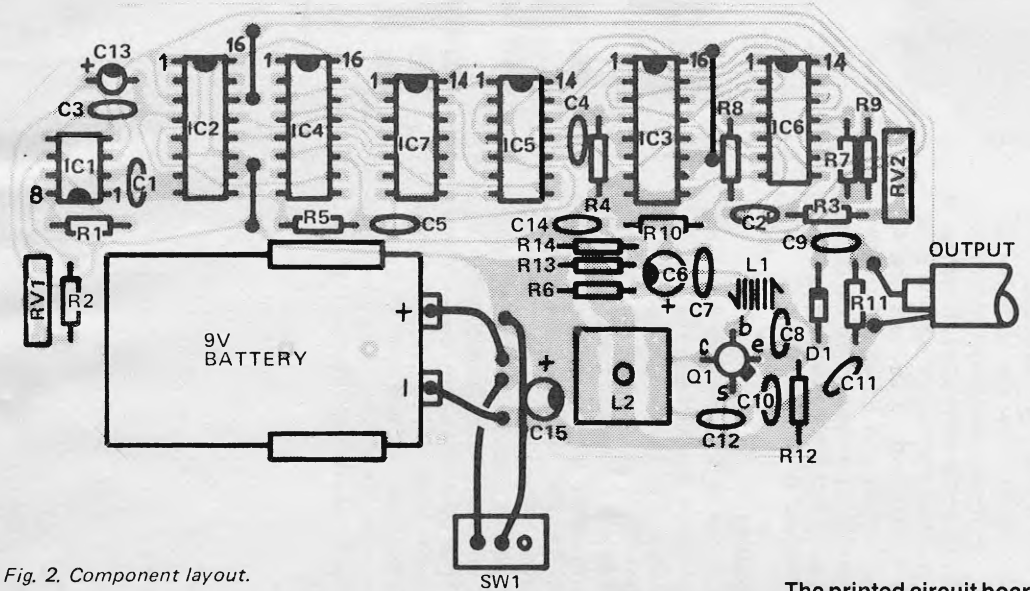


Fig. 2. Component layout.

The printed circuit board artwork for this project is on page 57.

PARTS LIST ETI – 717

Resistors all ¼W, 5%
- R1 . . . . . 1k
- R2 . . . . . 4k7
- R3–R5. . . . 10k
- R6 . . . . . 27k
- R7 . . . . . 10k
- R8, 9 . . . . . 4k7
- R10. . . . . 330R
- R11. . . . . 82R
- R12. . . . . 1k
- R13. . . . . 4k7
- R14. . . . . 3k3

Potentiometers
- RV1 . . . . . 5k trim
- RV2 . . . . . 25k trim

Capacitors
- C1. . . . . 180p ceramic
- C2. . . . . 22p ceramic
- C3. . . . . 10n polyester
- C4, 5 . . . . . 100p ceramic
- C6. . . . . 33μ 16V tantalum
- C7. . . . . 100p ceramic
- C8. . . . . 10p ceramic
- C9. . . . . 100p ceramic
- C10. . . . . 10p ceramic
- C11. . . . . 1n0 polyester
- C12. . . . . 1p0 ceramic
- C13. . . . . 33μ 16V tantalum
- C14. . . . . 100p ceramic
- C15. . . . . 33μ 16V tantalum

Inductors
- L1. . . . . see table 1
- L2. . . . . see table 1

Semiconductors
- IC1 . . . . . NE555
- IC2, 3. . . . . 4027B (CMOS)
- IC4 . . . . . 4040B (CMOS)
- IC5 . . . . . 4011B (CMOS)
- IC6 . . . . . 4001B (CMOS)
- IC7 . . . . . 4012B (CMOS)

Note: all CMOS should be 'B' series

- Q1 . . . . . BF180
- D1 . . . . . 1N914

Miscellaneous
- PC board ETI 717
- Zippy box
- Output socket
- Single pole toggle switch
- 9V battery

The ETI 717 generator produces a combined horizontal and vertical sync waveform and this, together with the crosshatch video, is modulated onto a carrier frequency operating in VHF channel 8 (189.25/194.75 MHz). Thus to use the generator one simply attaches it to the antenna terminals and selects channel 8.

Construction

Assemble the pc board according to the overlay starting with the links, resistors and diodes. The 555 IC, the transistor, capacitors and coils next with the CMOS IC's last. Solder the power supply pins of the CMOS (7 and 14 or 8 and 16) first. This allows the internal protection diodes to protect the inputs of these ICs.

We mounted the unit into a zippy box as it is cheap and available. This does however allow the oscillator to drift due to the presence of hands, etc., as it does not provide good shielding. If the crosshatch generator is going to be used continuously a die cast box is recommended. A teflon or rubber locking strip is necessary on the adjustable coil L2 as slight movement of the slug will put it off frequency.

Alignment

This is easiest if a frequency counter or oscilloscope is available. Monitor the output on pin 1 of IC4 and adjust RV1 to give 50 Hz.

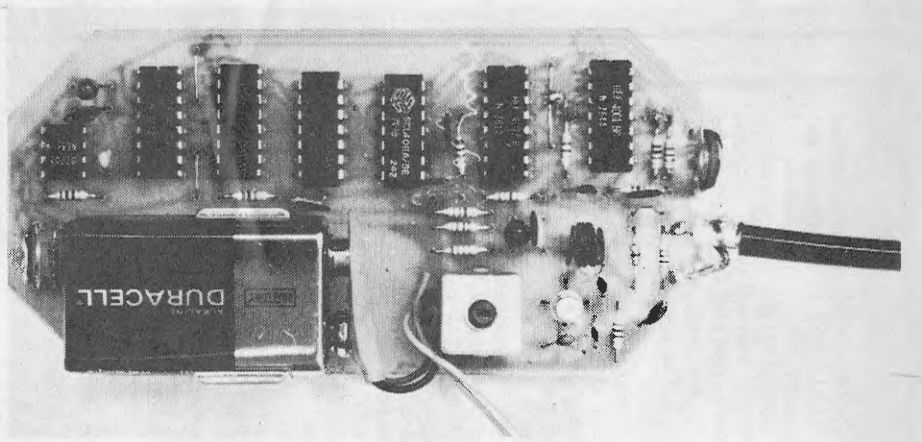
Connect the unit to the TV set and select channel 8 (or an unused channel from 7 to 10). Switch on and adjust L2 to give a stable picture. RV2 should be adjusted to give vertical lines of about the same width as the horizontal.

If an oscilloscope or counter is not available adjust L2 first to tune channel 8 as best you can and then RV1 to syncronize the picture. Now fine adjust both of these controls to give the best result.

Table 1
Coil Winding Data

L1 6 turns 0.5 mm enamelled wire close wound, 5 mm dia, air core.

L2 4 turns 0.5 mm enamelled wire close wound onto a miniature Neosid former with VHF slug, 6 pin base and aluminium can.
Terminate leads on opposite sides of the base. Use teflon locking strip on core.



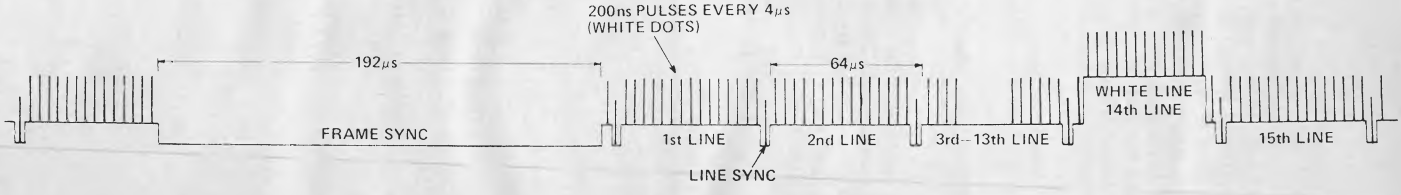


Fig. 3. Diagram showing part of the video waveform across R10. Due to the time scale involved (200ns wide pulses and 20ms between frame sync pulses) it is not possible to show the entire waveform. The first white line is the 14th and is then every 16th line.

SWR/power meter

New design provides wide sensitivity range and wide bandwidth.
By Roger Harrison VK2ZTB and Phil Wait VK2ZZQ

THIS REFLECTOMETER DESIGN, apart from being simple, elegant and easy to construct, covers three decades – from 100 kHz to 100 MHz, and can be constructed for RF powers as low as 500 mW or up to 500 watts.

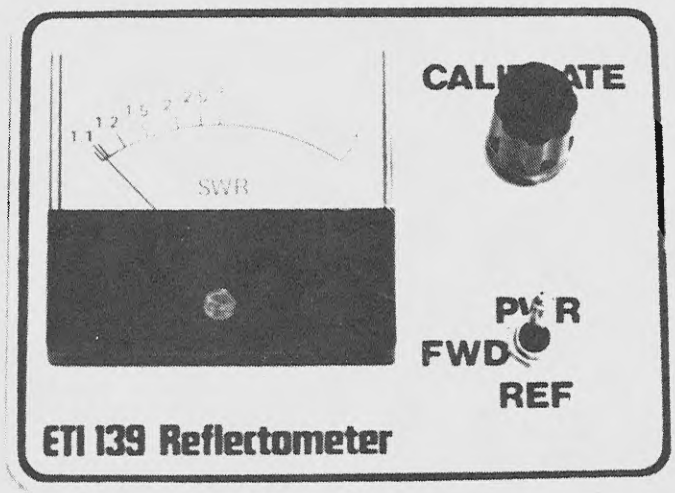
The problem with most designs for reflectometers, or "Swar" meters as they tend to be called colloquially these days, is that they generally only cover about one decade in frequency range – usually 3 to 30 MHz or, if further, have discontinuities and drastic sensitivity variations at the extreme ends of their frequency range.

Sensitivity is a problem with the commercially available instruments also. Those with the best sensitivity – 5W full scale usually – are made for the CB market, and while they will work over most of the HF spectrum (some extending beyond that), sensitivity is insufficient if you are working with low power solid state RF circuitry or doing a deal of antenna experimentation.

Performing antenna measurements at powers of 5W or more is discourteous to say the least, especially where sustained or many consecutive measurements need to be made.

The reflectometer/RF power meter described meets the requirements of most people involved in RF measurements requiring such an instrument and where a disparate variety of facilities are required.

This project will be extremely useful to radio amateurs, CBers, servicemen involved in communications, in laboratories etc.



CONSTRUCTION

Construction is very straightforward. The printed circuit design given is recommended, otherwise variations in layout may affect performance.

All the components are mounted on the *copper side* of the pc board, which is subsequently assembled onto the coax sockets and mounting bolts.

Commence by winding the toroid current transformer secondary turns. Refer to the circuit diagram. Cut a 45 mm length of RG58, stripping back the braid and insulation as illustrated in the component overlay and photographs. This is not all that critical, but maintain as much braid as you can to reduce problems with errors creeping in at the top end of the frequency range due to discontinuities here.

Slip the toroid over the short length of coax and mount this assembly on the pc board. Position the toroid centrally and fix it in place with a small amount of pliable plastic cement compound such as "Silastic".

Mount all the other components next. Pay particular attention to the orientation of the diodes D1,D2,D3.

The trimmer capacitor, C2 is shown

as a mica compression type. Any suitable trimmer – such as the Philips film trimmers – can be used, however, the mica compression trimmer provides a certain amount of 'vernier' adjustment.

The pc board and major components are assembled into a suitable metal box. We used a Horwood type 34/2/D which measures 100 mm by 75 mm by 50 mm. This provides for a compact finished instrument without a crowded layout.

The completed pc board is mounted in the following way:

Once the coax sockets are mounted, and the two mounting bolts are in position, a coax plug (with cable) should be plugged into each of the sockets in order to locate the centre-conductor pins of each socket.

The pc board is then placed into position and the input/output pads soldered to the coax socket pins. make sure that a good fillet of solder secures the pin to the pc board pad.

Two nuts on the mounting bolts, one under the pc board, one on top of the pc board, then secure the board mechanically as well as providing a ground connection. Refer to the pictures and component overlay.

Connections to the meter, pot, and switch – located on the front panel, can then be made with short lengths of hookup wire.

CALIBRATION

A suitable RF source, a dummy load and an RF voltmeter or a known-accurate RF power meter are required for test and calibration of the instrument.

Suitable low power dummy loads, marketed for CBers, are readily available or any of the standard amateur texts (ARRL, RSGB handbooks etc) provide excellent construction details of dummy loads to dissipate a variety of powers. The same texts describe suitable RF voltmeter probes that may be used in conjunction with a multimeter.

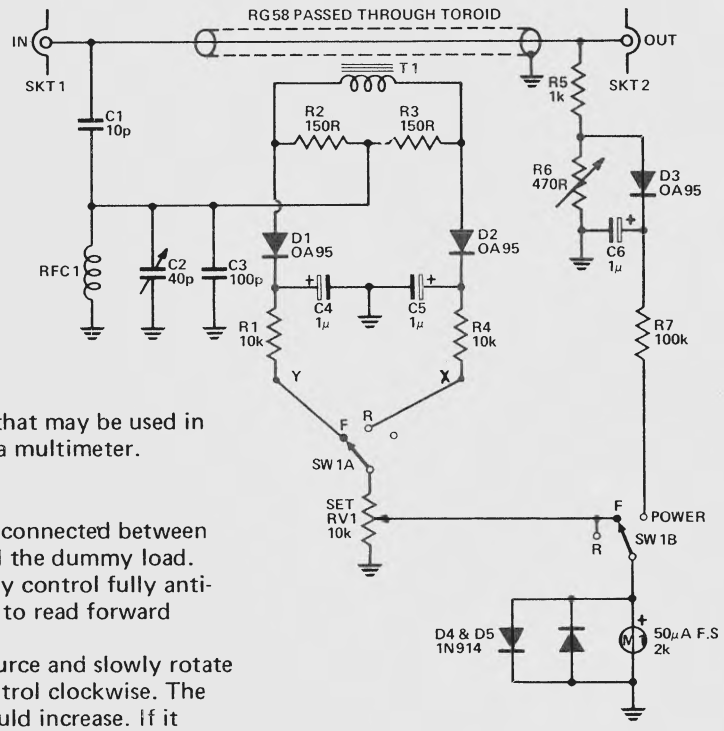


Fig. 1. Circuit diagram of the SWR/Power meter. Note the unusual switch configuration. A special C & K toggle switch was used as it provides the simplest operation. Otherwise, a double-pole, triple-throw switch is necessary.

SWR Scale

The instrument is connected between the RF source and the dummy load. Turn the sensitivity control fully anti-clockwise. Switch to read forward power.

Key the RF source and slowly rotate the sensitivity control clockwise. The meter reading should increase. If it doesn't, check wiring. If it goes in reverse, you've got D1 back to front!

If all is well, advance the sensitivity control until the meter reads full scale. Switch to read reverse power. Adjust the trimmer C2 to obtain a minimum meter reading. It should go to zero; increase the sensitivity when a very low reading is reached to ensure that C2 is adjusted correctly.

This completes the adjustment of the Reflectometer section. The scale calibration can be obtained from Table1.

The scale on the meter may be hand-lettered using Letraset or other 'rub-on' lettering. The original lettering may be painted over and the new SWR scale inserted beneath the original scale. Kit suppliers may make a whole new scale available.

Power

The circuit (Figure 1) shows a divider network, consisting of R5 and R6, tapped across the RF on the coax line.

The lower divider resistance R6 is shown as a variable element. A miniature deposited carbon track trimpot was used in the prototype. The low value types seem to perform quite well over a wide frequency range and one was used here for convenience. It was set so that the full-scale reading of M1 corresponded to a particular peak power dissipated by the dummy load (as measured with an RF voltmeter or known-accurate RF power meter).

Fixed resistors may be substituted for a trimpot, necessitating only a check of the accuracy of the full scale peak power reading. Values for particular full-scale power readings are given in Table 2.

The power scale should be calibrated to suit the individual instrument. It will be non-linear, particularly at the bottom end.

Performance

The inherent impedance of the prototype instrument was measured using a TEK 5 W dummy load and a Hewlett-Packard vector impedance voltmeter. The results are illustrated in Figure 4.

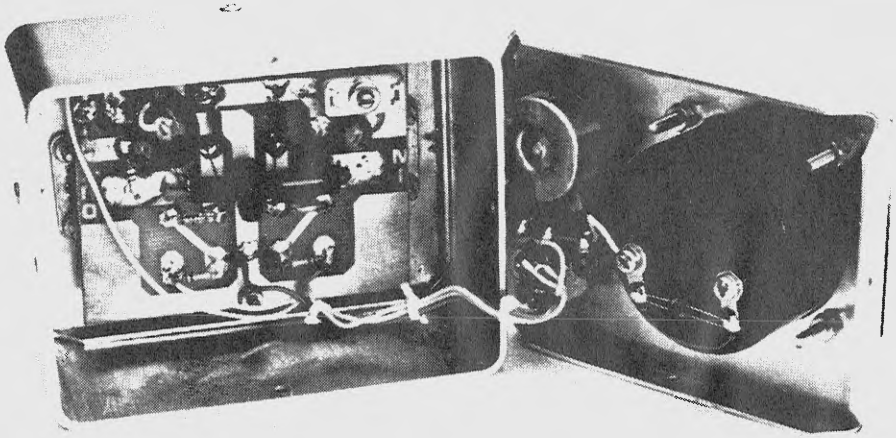


TABLE 1

SWR	Scale reading
3:1	0.5 full scale
2.5:1	0.42 full scale
2:1	0.34 full scale
1.5:1	0.2 full scale
1.2:1	0.1 full scale
1.1:1	0.05 full scale

TABLE 2

Peak Power, full scale	R2 value
500 W	6R8
200 W	2 x 33R in parallel
100 W	33R
50 W	68R
20 W	2 x 330R in parallel
10 W	330R
5 W	680R
3 W	1k + 100R in series *

*linearity suffers

The printed circuit board layout for this project is reproduced on page 59.

PARTS LIST – ETI 139

Resistors all ¼W, 5%
R1 . . . . . 10k
R2,R3 . . . 150R
R4 . . . . . 10k
R5 . . . . . 1k
R6 . . . . . 470R trimpot or fixed —see text
R7 . . . . . 100k

Potentiometer
RV1 . . . . 10k/C pot

Capacitors
C1. . . . . 10p ceramic
C2. . . . . 40p trimmer
C3. . . . . 100p ceramic
C4 - C6 . . . 1μ solid dipped tantalum

Semiconductors
D1 - D3. . . OA95
D4,5 . . . . 1N914

Miscellaneous
RFC1. . . . Any moulded RF choke, 1mH or more (value not critical).
SW1. . . . . C & K switch type 7211 (see text)
M1 . . . . . 50 μA meter, T.E.W. type, 2k resistance.
T1. . . . . 40 turns of 35 gauge B & S enamelled wire, around circumference of Neosid toroid type 28-511-31, 12.7 mm o.d., 6.35 mm i.d., 3.18 mm thick, F14 material (see text)
Coax sockets . . . SO239 or other type to suit
Case. . . . . Horwood type 34/2/D (100 mm x 75 mm x 50 mm).
PC board . . ETI 139
Two 25 mm long bolts with three nuts and two lock washers each; nuts and bolts for coax sockets (if required); length of RG58 coax; 6 mm dia. sleeving; hookup wire, etc.

How it works – ETI 139

The reflectometer employs a "current transformer" having an electrostatically-shielded primary with a high-ratio secondary winding driving a low value load resistance.

A short length of coaxial cable, passed through a ferrite toroid, forms the primary with the braid connected so as to form an electrostatic shield.

The secondary of the current transformer consists of a winding around the circumference of the toroid, coupled to the magnetic component of the 'leakage' field of the short length of coax cable.

The secondary drives a centre-tapped resistive load (R2/R3) connected to a voltage sampling network (C1-C2/C3) tapped across the RF input such that sum and difference voltages will appear across the ends of the current transformer (T1) secondary winding.

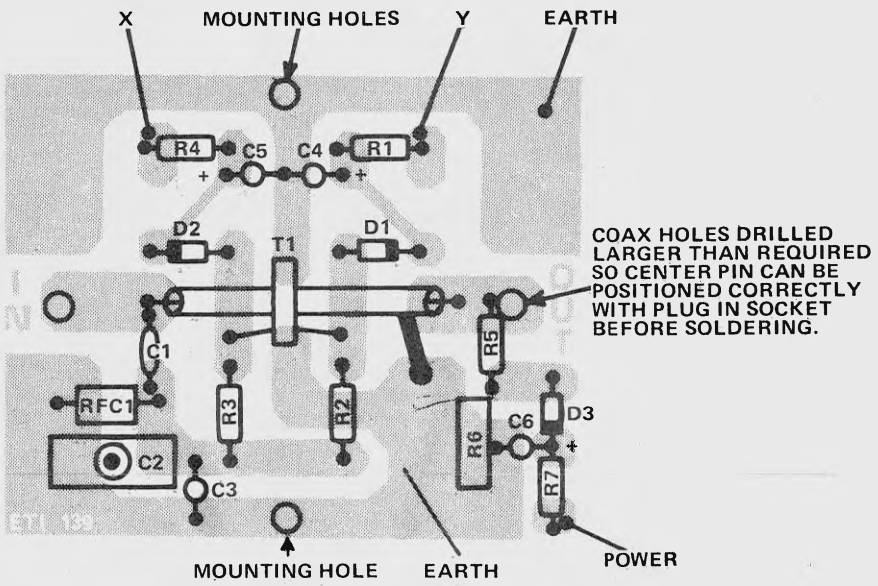
Diodes D1 and D2 rectify the sum and difference voltages from the secondary of T1, RF and audio (modulation) bypassing being provided by C4 and C5. The RF choke, RFC1, provides a low-resistance DC return for the signal rectifiers, D1 and D2.

The power measurement facility is obtained by tapping off a portion of the RF voltage on the line via R5 and R6, and rectifying this with D3. Capacitor C6 provides RF and audio (modulation) bypassing.

As the load on the rectifier is so light – R7 being 100 k and the meter being 2 k, peak power is measured.

Diodes D4 and D5 provide protection for the meter.

Fig. 2. Component overlay for the pc board. Note that, contrary to the usual practice, the components are mounted on the copper *side of the board.*



The impedance discontinuities introduced by the prototype are well inside the basic accuracy capability of the meter movement! The real part of the instrument's impedance is within 5% of the nominal 50 ohms — most of this is probably due to connectors and construction discontinuities.

The variation in the real part of the impedance is within +/- one ohm across the frequency range of the instrument, and can be essentially ignored.

The reactive (imaginary) component of the instrument's inherent impedance is negligible up to 20 MHz when it begins to become slightly capacitive.

The overall impedance decreases rapidly above 100 MHz.

Sensitivity and sensitivity bandwidth of the prototype is excellent. The half-power points of the sensitivity bandwidth of the reflectometer are at approximately 350 kHz and 25 MHz.

Full-scale deflection at 27 MHz requires 0.8 watts into 50 ohms. Mid-band sensitivity is under half a watt!

Modifications

For higher power applications, the basic sensitivity of the reflectometer can be reduced by one of several methods, or a combination.

If you are working with powers around 20 to 50 watts, R2 and R3 can be reduced to 47 ohms. For higher powers, the number of turns on the toroid can be reduced, and R2/R3 further reduced in value. As a guide, reduce the secondary of T1 to 20 turns and R2, 3 to 47 ohms. Everything else remains unchanged. This should suit power levels of 200 watts and higher.

Other types of coax sockets can be used, such as the BNC, type N or the inexpensive Belling-Lee sockets. No modifications to the pc board are necessary, however, mounting details of the sockets and board will need to be altered to suit.

The basic reflectometer construction is so simple and inexpensive that several can be built and installed to provide remote SWR/RF-output monitoring of antenna installations.

The RF portion can be mounted at a convenient place and the reflectometer output leads X and Y taken to remote metering facilities. Power output measurement circuitry is probably superfluous in these circumstances.

Protection circuitry for transceivers and power amplifiers may be simply realised using the basic reflectometer circuit and activating protection devices by comparing the output voltages of D1 and D2.

Swept VSWR measurement can be accomplished using the basic reflectometer circuit. The differential output from D1/D2 can be used to drive the vertical axis of a CRT display (via suitable amplification), the horizontal axis being driven by the sweep voltage of a voltage-controlled signal generator. Voila! - swept VSWR measurements.

Accurate SWR measurements for VSWR values below 2:1 can be made by driving an expanded-scale differential voltmeter circuit that measures the output difference between D1 and D2. This technique is well illustrated in reference 2.

This type of instrument is particularly useful when making VSWR performance plots of antennas over a narrow bandwidth (providing they closely match 50 ohms in the first place).

This reflectometer technique can also be used to measure power. However, the authors opted for the diode RF voltmeter method as it is somewhat more versatile, and is unaffected by the sensitivity bandwidth of the toroidal current transformer. See the two references for more details.

The sensitivity bandwidth may be shifted up in frequency by a decade or more, such that it rolls off around 1 MHz and 50 MHz, by employing a toroid for T1 of the same dimensions but made of F25 material.

References

Whilst not the 'definitive' texts on this type of reflectometer, these two references provide good practical sources of information.

1. "Frequency Independent Directional Wattmeters"; P.G. Martin, Radio Communication (RSGB journal), July 1972.
2. "Test Equipment for the Radio Amateur", H.C. Gibson G8CGA, published by the RSGB, 1974.

Note: The manufacturers of the toroid, Neosid Limited (Australia), are located at 23/25 Percival Street, Lilyfield NSW. However, components suppliers such as Davred and Dick Smith's may have them in stock *— but accept no substitutes!*

Fig. 3. The meter, sensitivity pot and switch connections. Leads X and Y go to D2 and D1 respectively, while the lead marked 'POWER' goes to R7. Refer to figure 2.

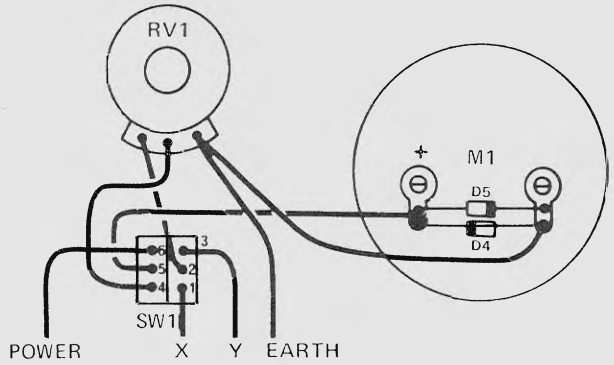
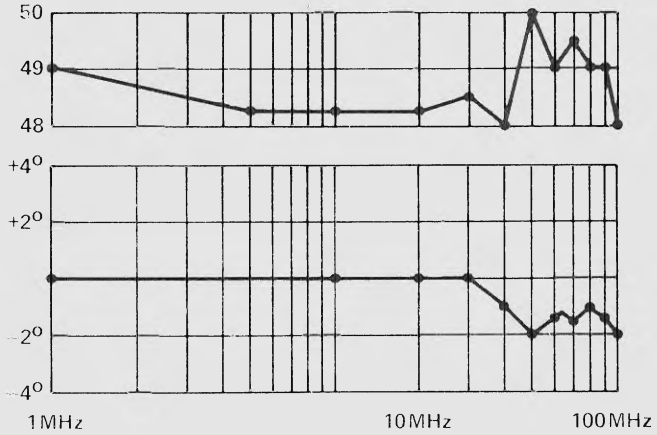


Fig.4. Top: real or resistive component of the prototype's inherent impedance. Lower. Reactive component.



RF signal generator

AN RF SIGNAL generator is an invaluable instrument for AM radio servicing and alignment – it greatly simplifies alignment and allows each stage to be checked for gain and frequency response.

Three types of signal are required for these purposes. Firstly, we require an audio signal to check that part of the receiver from the volume control (after the detector) to the speaker. Secondly, we need a modulated RF signal at 455 kHz (430 to 480 kHz available for non-standard receivers) for checking and aligning IF stages, and lastly, we need a modulated RF signal in the range 500 to 1600 kHz to check out the RF amplifier and converter.

In addition the level of the generator output should be adjustable so that AGC action may be checked out, and so that optimum levels may be chosen for servicing and gain checks. All the above requirements are met by the ETI 129 generator and, since only one of the available signals is used at any one time, a common level control is used for all these outputs.

In our generator the provision of IF frequencies from 430 to 480 kHz, as well as catering for non-standard receivers, allows receiver IF selectivity to be checked.

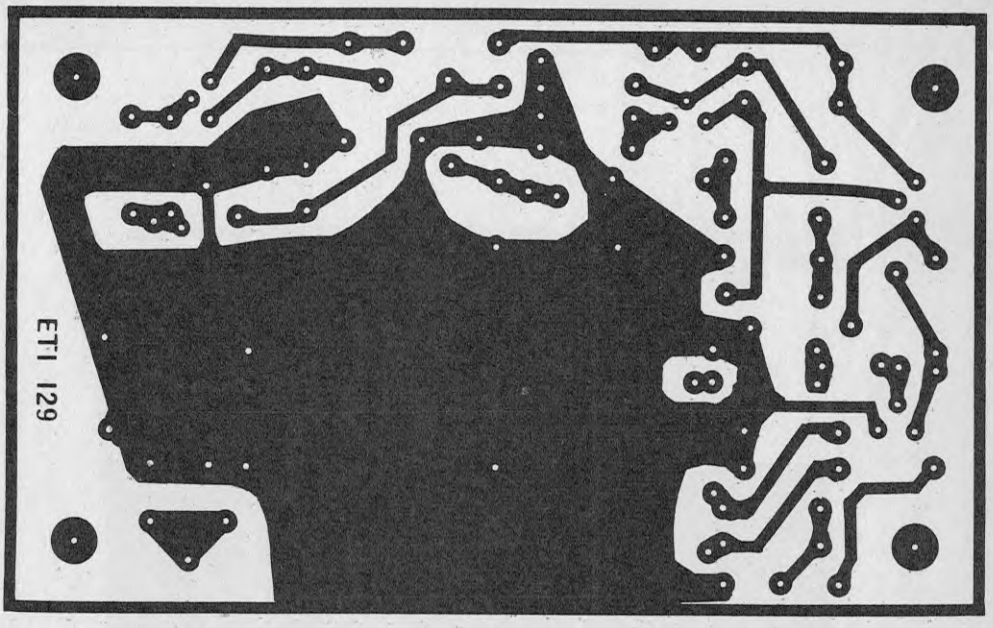
CONSTRUCTION

The prototype instrument was mounted in an aluminium box having external dimensions of 145 x 115 x 90 mm. Layout of the circuitry is important and for this reason the printed-circuit board layout provided should definitely be used. Take care when assembling components to the printed-circuit board to correctly orientate capacitors C9, C11 and C15, transistors Q1 to Q4 and diode D1.

The variable capacitor is mounted onto the component side of the printed-circuit board but spaced from it by about 2 mm (an oversized nut may be used). The mounting of the board and variable capacitor assembly to the front panel and reduction-drive assembly may best be understood by referring to Fig. 3. Note that the board is mounted by four standoffs and that rubber grommets are used to allow the board to move slightly – for this reason the screws should not be tightened too much. This method is used to avoid the expense of using a flexible drive to the variable capacitor.

The six-to-one slow-motion drive is mounted to the front panel by two 15 mm long bolts. The drive is spaced back from the front panel by 4 mm long spacers.

The remaining controls are mounted straight onto the front panel as shown in the photograph.



Printed-circuit board layout.
Full size 129 x 80 mm.

CALIBRATION

High Range. Using a conventional AM receiver tune to a station at the top end of the frequency band. Set the pointer of the RF generator to indicate the frequency of the station being received and couple the generator to the receiver

Adjust capacitor C3 until the signal from the generator can be heard interfering with the station. This will take the form of a whistle which, as C3 is tuned, will go from a high frequency to a low frequency and then back to a high frequency again. The correct tuning point is where the frequency is at its lowest, i.e. in the middle. The level of the generator signal may have to be increased to obtain the correct point with accuracy. This procedure is called

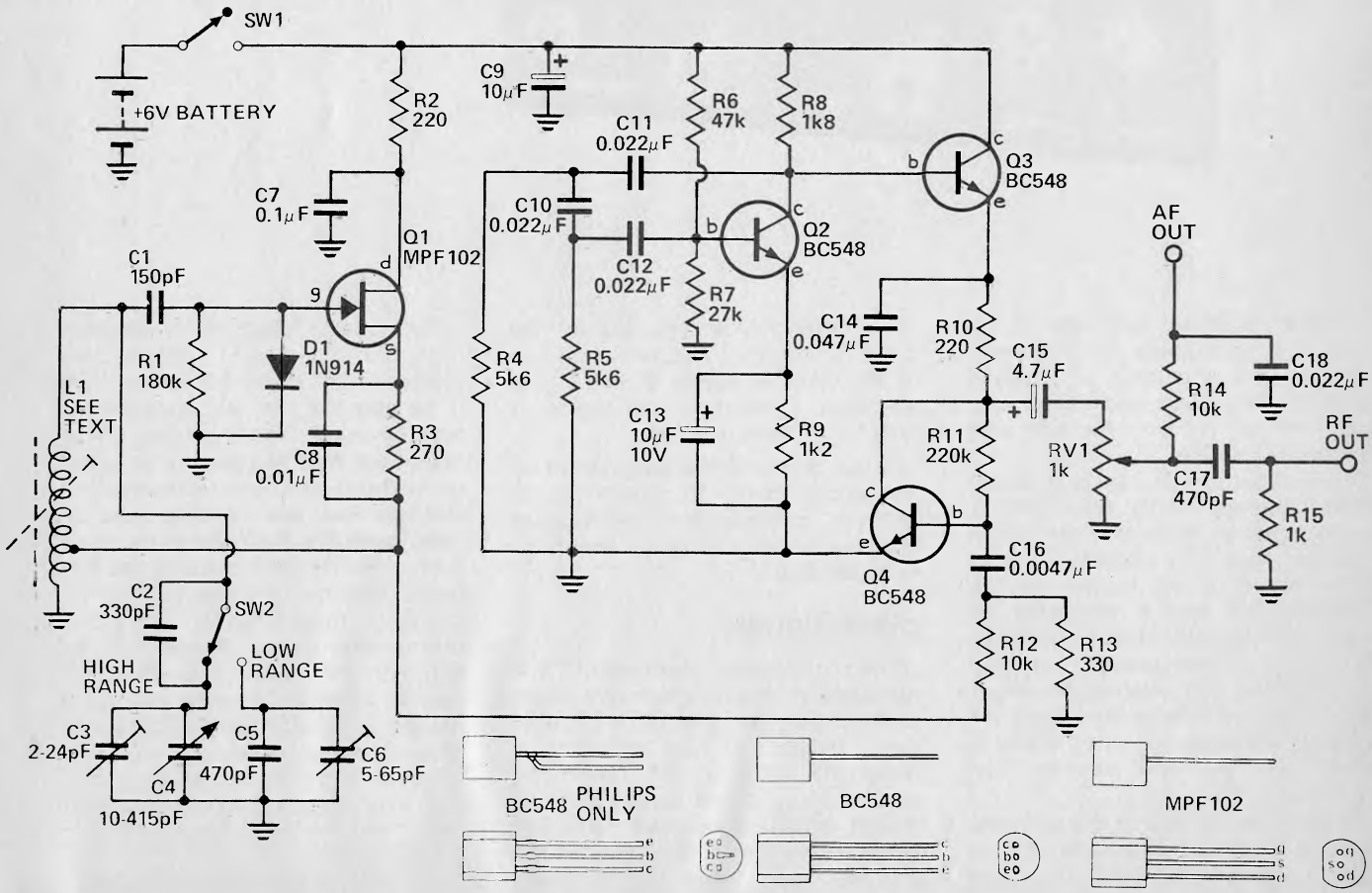


Fig. 1. Circuit diagram of the modulated RF generator.

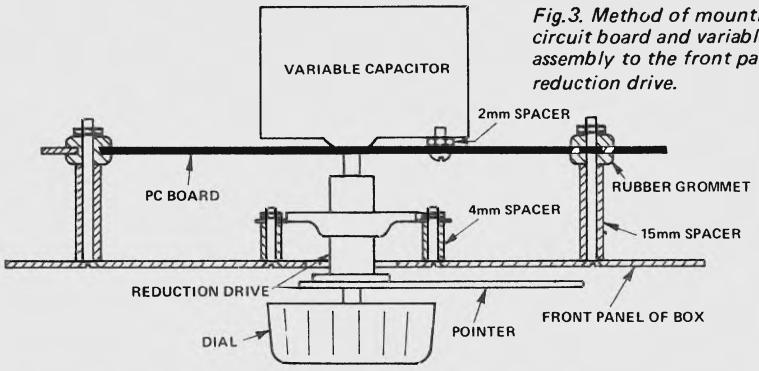


Fig.3. Method of mounting printed-circuit board and variable capacitor assembly to the front panel and reduction drive.

PARTS LIST — ETI 129

R2,10	Resistor	220	¼W 5%	C10,11	Capacitor	0.022μF	polyester
R3	"	270	" "	C12,18	"	0.022μF	polyester
R13	"	330	" "	C14	"	0.047μF	polyester
R15	"	1k	" "	C7	"	0.1μF	polyester
R9	"	1k2	" "	C15	"	4.7μF	10V electro-lytic
R8	"	1k8	" "	C9,13	"	10μF	10V electro-lytic
R4,5	"	5k6	" "				
R12,14	"	10k	" "	Q1	Transistor	MPF102	or similar
R7	"	27k	" "	Q2,3,4	"	BC548	or similar
R6	"	47k	" "				
				D1	Diode	IN914	or similar
R1	"	180k	" "				
R11	"	220k	" "	SW1	Switch	SPST	toggle
				SW2	"	SPDT	toggle
RV1	Potentiometer	1k Lin	rotary.				
				L1	Inductor	See table 1.	
C3	Capacitor	2-24pF Philips 2222-808-00006		PC board ETI 129			
C6	"	5-65pF Philips 2222-808-01001		Metal box 145 x 115 x 90 mm			
				Front panel			
C1	"	150pF ceramic		6 to 1 Reduction drive.			
C2	"	330pF ceramic		Four rubber grommets			
C4	"	10-415pF Roblan variable		Four 15mm long spacers*			
				Two 4mm long spacers*			
				Two 2mm long spacers*			
C5,17	"	470pF Ceramic		Three terminals (red, black, green)			
C16	"	0.0047μF polyester		Nuts & bolts etc.			
C8	"	0.01μF polyester		*Spacers may be cut from longer sections.			

'zero beating'.

Now tune the receiver to a station at the low end of the band. Again set the pointer of the RF generator to the frequency at which the station operates and adjust the slug of L1 for zero beat in the same manner as for the high end.

Repeat the procedure for both the high and low ends of the band until there is no change at either end.

Low Range. The low range should be calibrated after the high range calibration has been completed.

First set C6 to mid position. Then tune in a station on a broadcast receiver that lies somewhere between either 860 and 960 kHz or 1290 and 1440 kHz. These two bands are twice and three times the generator IF band respectively. That is, we are working on the second or third harmonic of the generator respectively. Divide the actual frequency of the tuned-in station by two (for stations between 860 kHz and 960 kHz) or by three for stations between 1290 and 1440 kHz. Now set the pointer on the RF generator to this frequency. Adjust the capacitor C6 for zero beat as detailed for the high range.

Refer to any standard textbook for alignment procedure for AM receivers.

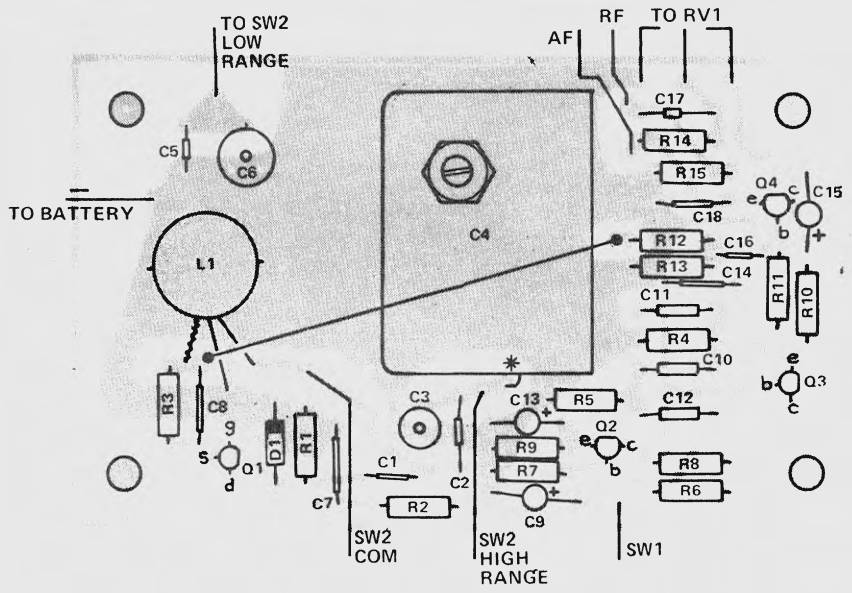


Fig. 2. Component overlay for the RF generator. Note the wire link between R12 and C8 which should be installed before fitting C4. Also note the connection from C4 to the board where shown by the asterisk.

HOW IT WORKS — ETI 129

The circuit may be sub-divided into three basic sections. These are:—

a) RF or carrier oscillator.

b) AF or modulation oscillator.

c) Modulator and buffer amplifier.

a) Transistor Q1 is connected as an Hartley oscillator. The positive feedback necessary for oscillation is provided from the source terminal of Q1 back to the gate via coil L1. The frequency of oscillation is determined by coil L1 in conjunction with capacitors C2 through C6.

Two ranges are provided, 500 kHz to 1600 kHz with L1, C3 and C4; and 430 to 480 kHz with L1, C2, C5 and C6. Diode D1 is used to develop a negative bias across R1 which thus limits the level of oscillation, and hence prevents damage to the gate of Q1.

b) Transistor Q3 is connected as a phase-shift oscillator. The network C10,C11, C12, and R3, R4 provides about 180° phase shift of the signal at the collector of Q3, and the feedback to the base of Q3 is therefore positive – causing oscillation. The frequency of oscillation is about 600 Hz.

c) Transistor Q4 is a class 'A' amplifier which is biased by the half-supply method (R10 and R11) the operating supply being obtained from emitter-follower ,Q3. The output of Q3 is the sine-wave from the phase-shift oscillator. Because of R11 any change at the junction of Q3 and R10 causes a corresponding change in the emitter current of Q4. The emitter current of Q4 therefore varies at the rate of 600 Hz. The emitter resistance of a transistor depends on the emitter current of that transistor and the gain depends on the ratio of the collector load, R10 to the emitter resistance. Since the emitter resistance is varying at 600 Hz, the gain of the transistor will also be varying at 600 Hz and so the RF signal fed to the base of Q4 from Q1 by C16 is modulated by the audio signal.

The signal across R10 is fed to RV1 by C15 and this signal consists of two components – the modulated RF and the audio tone.

After attenuation by RV1 the signals are separated by high and low pass filters to the AF and RF outlets.

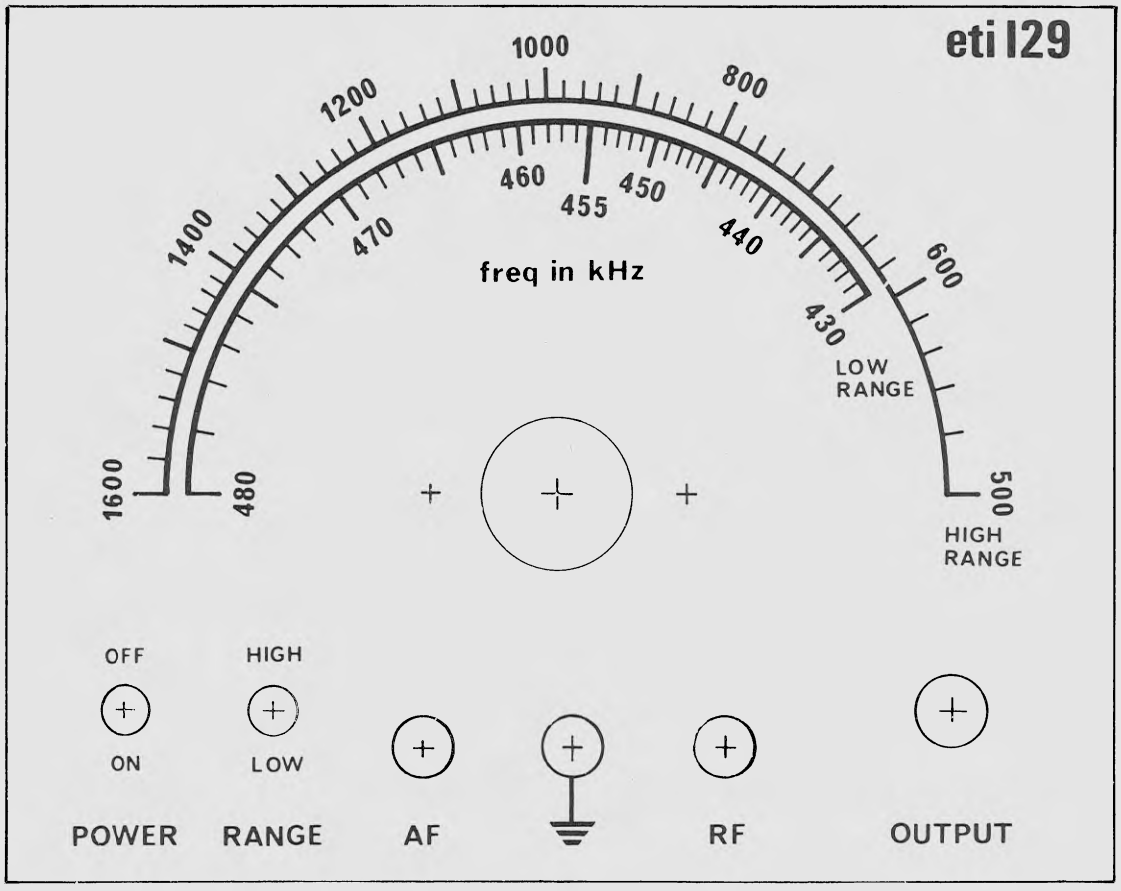


Fig. 4. Front panel artwork. Full size 148 x 116 mm.

COUPLING TO RECEIVER

Method 1. To ferrite rod coil. Connect one end of a length of ordinary hook-up wire to the RF OUT jack and then wrap about two turns of the other end of the wire around and over the aerial coil on the ferrite rod.

Method 2. To an IF amplifier. Connect a wire to the RF OUT jack and to its other end connect a 0.001 capacitor and a 1 k resistor in series. To inject the signal into the IF stage just connect the free end of the resistor to the base of the IF stage transistor.

In both the above methods if insufficient signal level is available an earth connection may also have to be made between the generator and the receiver.

Method 3. Audio testing. Use a length of wire as before but with a series capacitor of about 0.47μF. Note that an earth connection will definitely be required in this case. Once again the best place to inject a signal is straight into the base of the transistor.

Internal view of the generator.

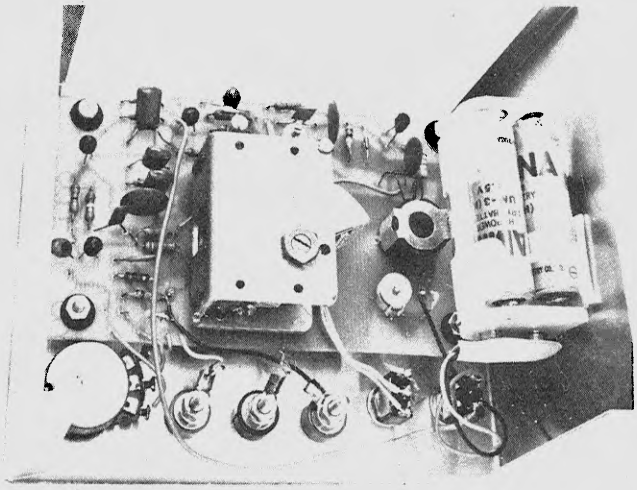


TABLE 1

L1	20 turns 0.5 mm enamelled copper wire tapped at four turns from grounded end.
CORE	Philip potcore P18 series, material 3B7 or 3H1, μe = 220. Part No 4322 – 022 – 24280 or 4322 – 022 – 24080
FORMER	4322 – 021 – 30270
ADJUSTOR	4322 – 021 – 31080
CLIP	4307 – 021 – 20000

One each of core, former, adjustor and clip required to assemble one complete coil.

Logic trigger

Debug complex logic circuitry with this unit.

WHEN USING AN oscilloscope to examine or fault find digital circuitry, it is often desirable to see what happens just before a pulse or edge occurs. An example of this is when measuring the propagation delay in a ripple counter. Here it is easy to trigger on the last output but the edge of the counter input which initiated the change in the output may have occurred over 100 ns earlier. Even with the delay line built into modern oscilloscopes the edge is too early to see.

Triggering on the input waveform allows this edge to be seen but if the output pulse occurs only once every thousand or so pulses it will not be seen. With this unit, the output of all the stages in the divider can be examined and a pulse can be generated anywhere in the cycle. By selecting a pulse very close to, but before, the edge in question and using it to trigger the oscilloscope (use ext trigger) both the clock waveform and output waveform can be seen.

With the advent of microprocessors it has become increasingly difficult to fault find as things happen (e.g. the CE input to a memory may go low) only when a particular address is given. As the address bus is always in motion it is almost impossible to trigger the scope on any one address. Again with this unit the address bus is interrogated along with the necessary write or read lines, and its output can be used to trigger the oscilloscope only when the correct sequence is received.

SPECIFICATION - ETI 141

Modes	Asynchronous or synchronous
No. of inputs	12 address, 1 clock
Loading	
address	0.4 UL (TTL)
clock	0.4 UL (TTL)
Pulse extension mono	10 ms
Pulse indication	LED
Minimum pulse detectable	<40 ns
Propagation delay	<45 ns
Trigger (synchronous)	positive or negative edge of clock input
Set up time (synchronous) address to clock	<40 ns
Output	logical "1" when input agrees with switch setting and/or clock (synchronous only)
Power requirement	+5V @ 50 mA

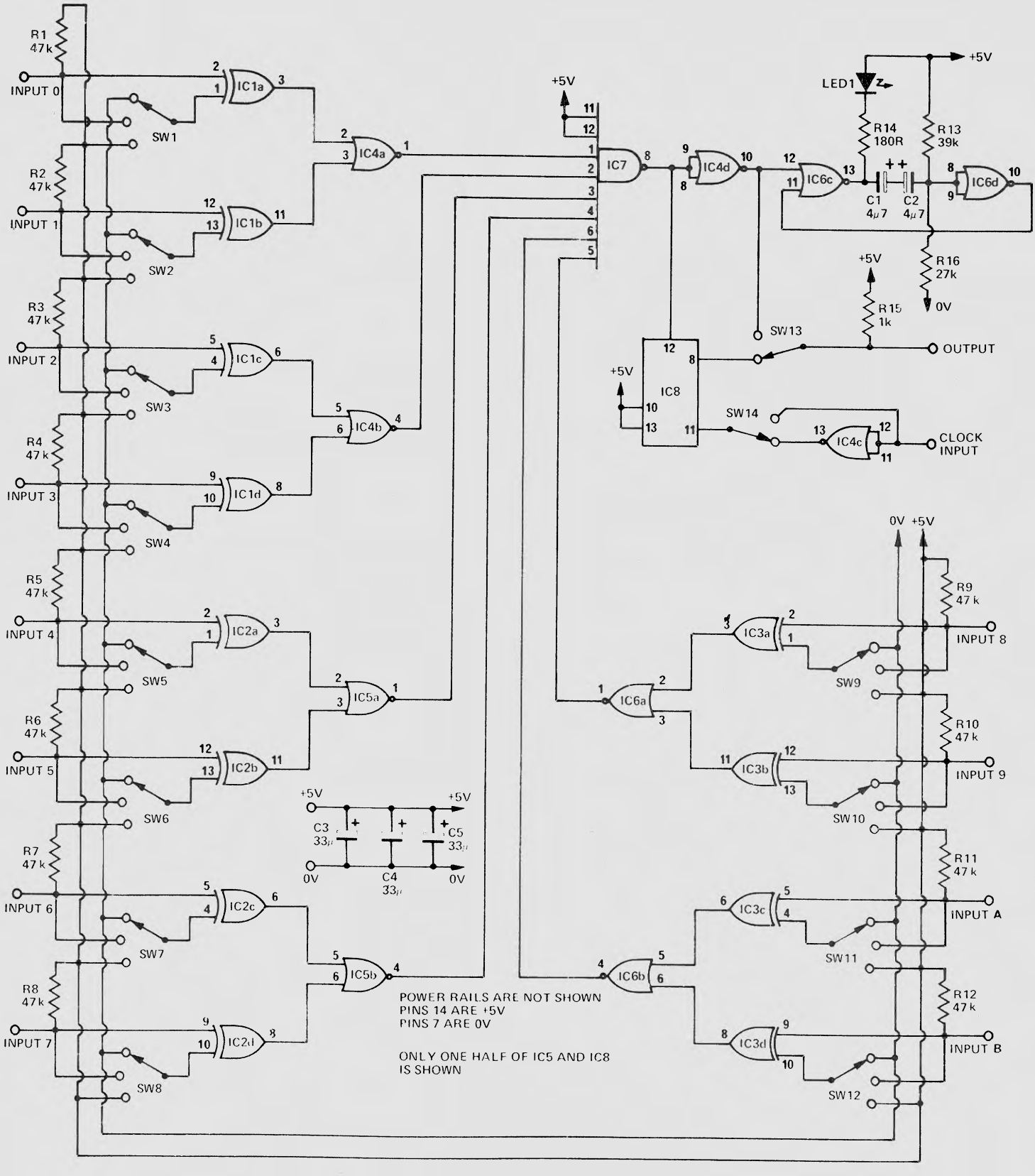


Fig. 1. Circuit diagram of the Logic Trigger.

PARTS LIST – ETI 141

Resistors all ½ W, 5%
R1–R12 . . . . 47k
R13. . . . . 39k
R14. . . . . 180R
R15. . . . . 1k
R16. . . . . 27k

Capacitors
C1,2 . . . . . 4μ7 25V electro
C3–C5 . . . . . 33μ 16V tantalum

Semiconductors
IC1–IC3 . . . . 74LS86
IC4–IC6 . . . . 74LS02
IC7 . . . . . 74LS30
IC8 . . . . . 74LS74
LED 1 . . . . . Red LED

Miscelaneous
PC board ETI 141
Twelve 3 position slide switches
Two 2 position slide switches
Front panel
Box to suit

HOW IT WORKS - ETI 141

The twelve inputs are compared to the levels set on the slide switches SW1-SW12 by the exclusive OR gates IC1-IC3. These ICs have a high output only if the two inputs differ. If they are the same, either both low or both high, the output will be low. If the two inputs are joined together, as when the switches are in the don't care position, the output will always be low.

The outputs from the exclusive OR gates are combined in pairs by the NOR gates IC4-IC6. If the 12 input signals match the preset selection, the output of all 6 NOR gates will be high. If any one is not in agreement with the selection one or more of the NOR gates will have a low output.

These NOR gate outputs are combined by IC7 which is an eight input NAND gate. The output of this gate will low only if all 12 inputs match. The output of this IC is inverted by IC4/d to provide the asynchronous output.

This output also triggers the monostable formed by IC6/c and IC6/d. This gives a 10 ms long pulse to light the LED indicating a pulse was received. If it is a steady state signal the LED will stay on.

The output of the NAND gate, IC7, also joins the data input of IC8 (D type flip flop). This IC is toggled on the positive edge of the clock waveform transferring the data to the output. This is the synchronous output. To allow for either positive or negative synchronization an inverter is used on the clock input and either polarity can be selected by SW13.

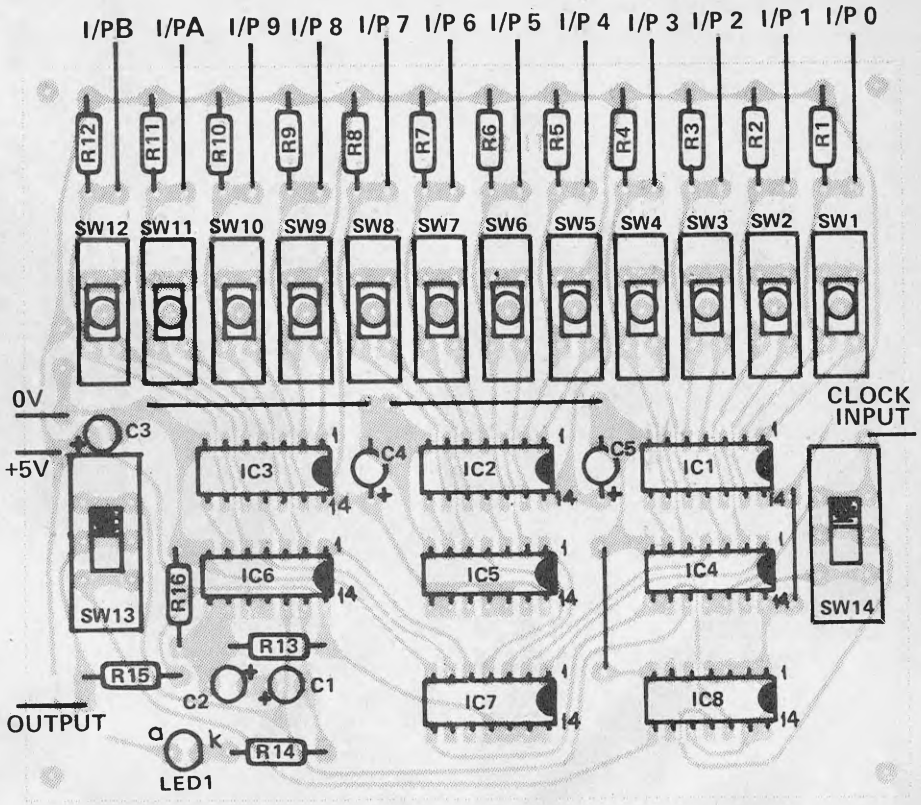


Fig. 2 Overlay of the PCB

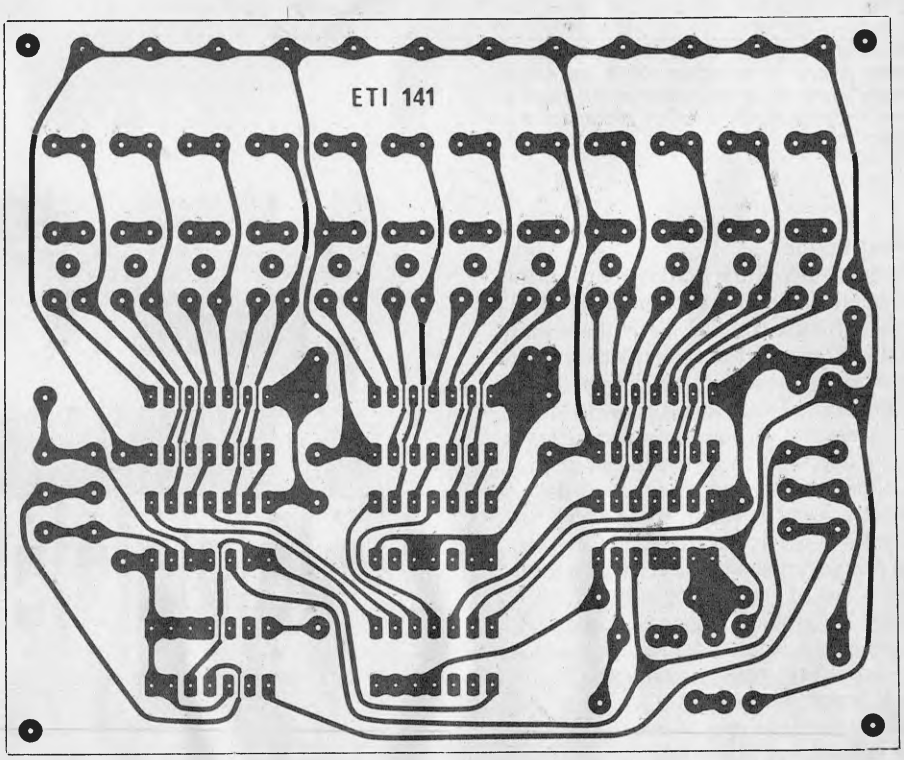


Fig. 3 PCB pattern shown full size.

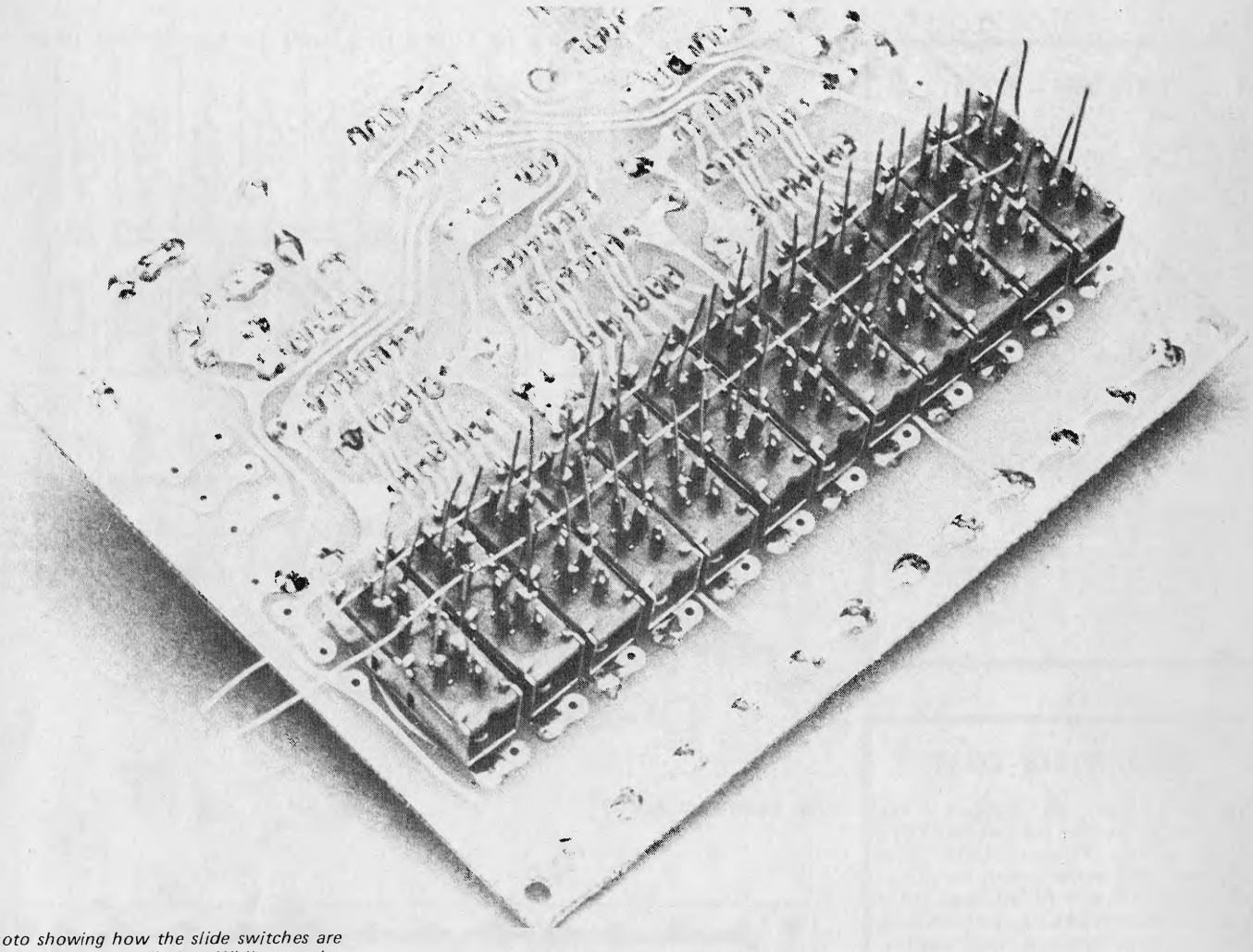
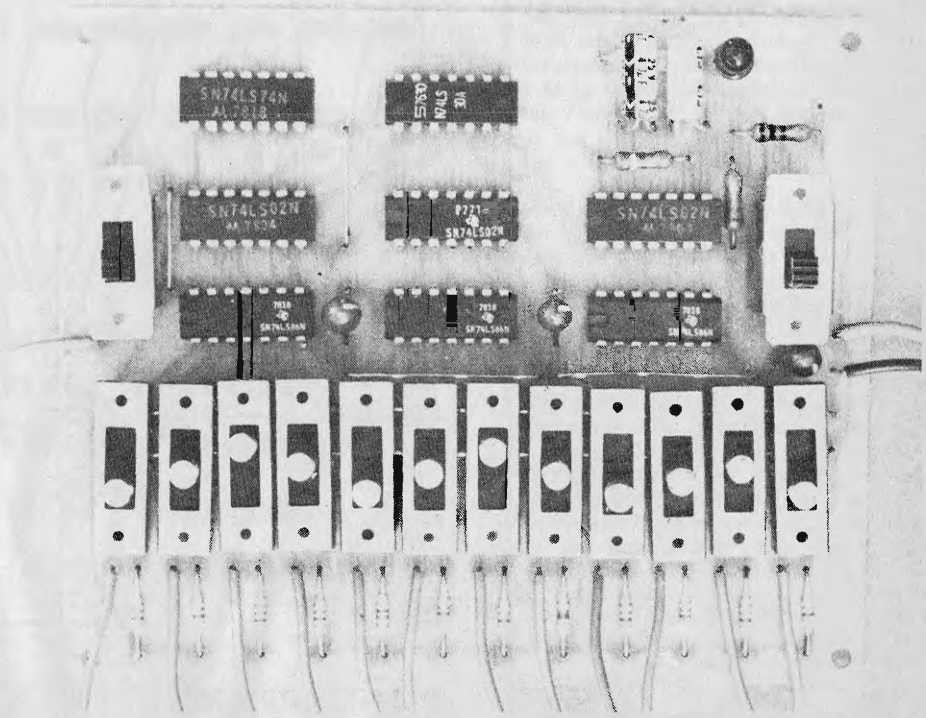


Photo showing how the slide switches are wired prior to installation. While our photo shows them on an assembled pc board it is best if they are wired before the board is assembled.



Construction

We mounted all the components on the pc board including the switches. The only difficult (fiddly) bit is the wiring of the three position slide switches which have to be preassembled before fitting to the pcb. The wiring is shown in fig.3.

To aid this we have provided 12 holes in the pcb the size of the toggle of the switches; if the switches are initially placed upside down in these holes the board will act as a template to provide the correct spacing. We have also used two wires of the second pole of the switch to provide mechanical support. While only a single pole switch is needed the only ones readily available (from Dick Smith) are two pole.

The switches can now be mated to the pc board with the two longitudinal wires being terminated in the holes provided at the end of the switch bank.

Versatile logic test probe

If you work or experiment with logic circuitry this project should be invaluable for debugging circuits. Inexpensive to build, it may be used both with TTL and CMOS circuitry, and indicates HI or LO conditions as well as pulse trains above 1 MHz. It will also detect short, isolated pulses having widths down to 500 ns.

Dr P. M. Kelly

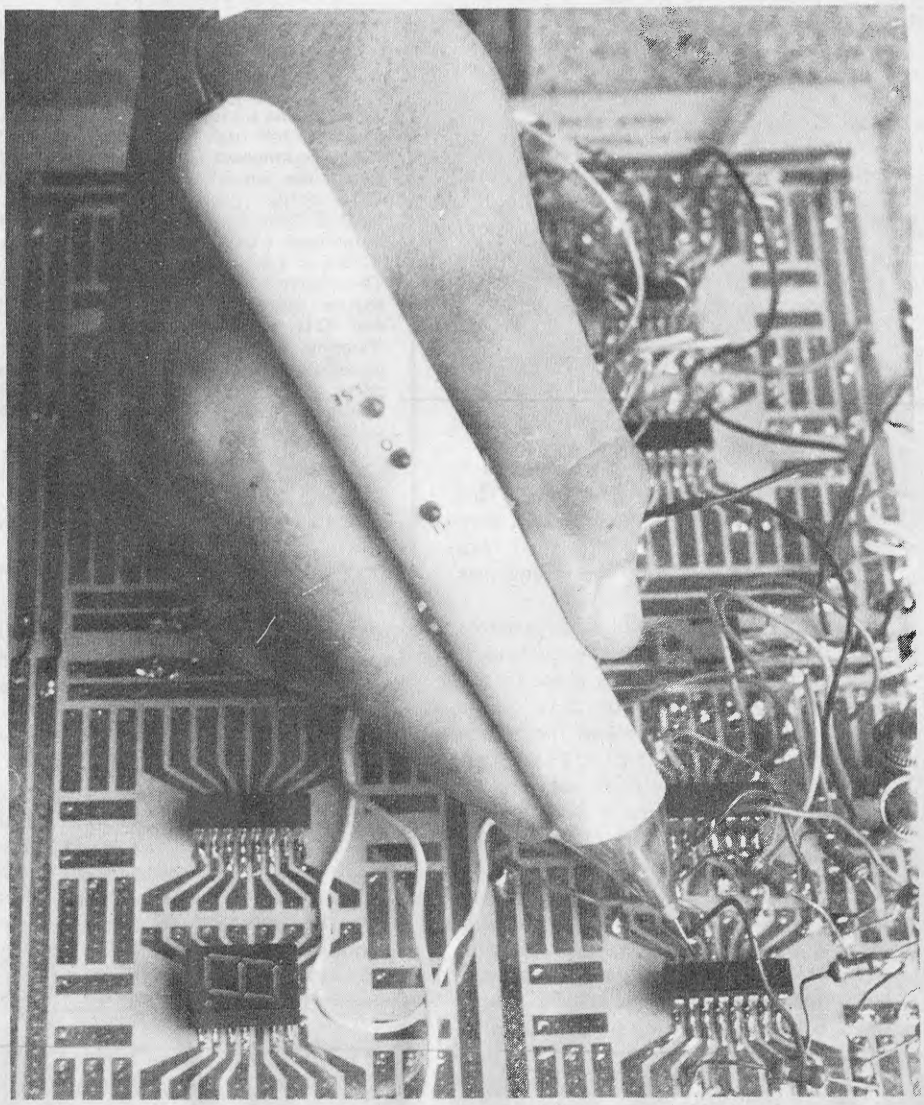
INTEREST in digital electronics has grown rapidly in the past few years with the advent of microprocessors and large scale integration. The most essential test instrument for experimenting with digital circuitry is a logic probe.

In its most basic form this should provide an indication of the logic level at any point in a circuit without overloading the section being tested. Other desirable features are the ability to follow high frequency pulse trains (preferably over 1 MHz) and to detect isolated, narrow pulses less than 1 μsec in width. Finally, the instrument should be compatible with both TTL and CMOS ICs and be able to operate from a wide range of supply voltages (say five to 15 volts).

Commercial logic probes that satisfy all these requirements are available, but they invariably cost over $30. The probe design described here offers comparable performance for less than $5, combined with an excuse to enjoy a good cigar – a cigar tube is used for the case!

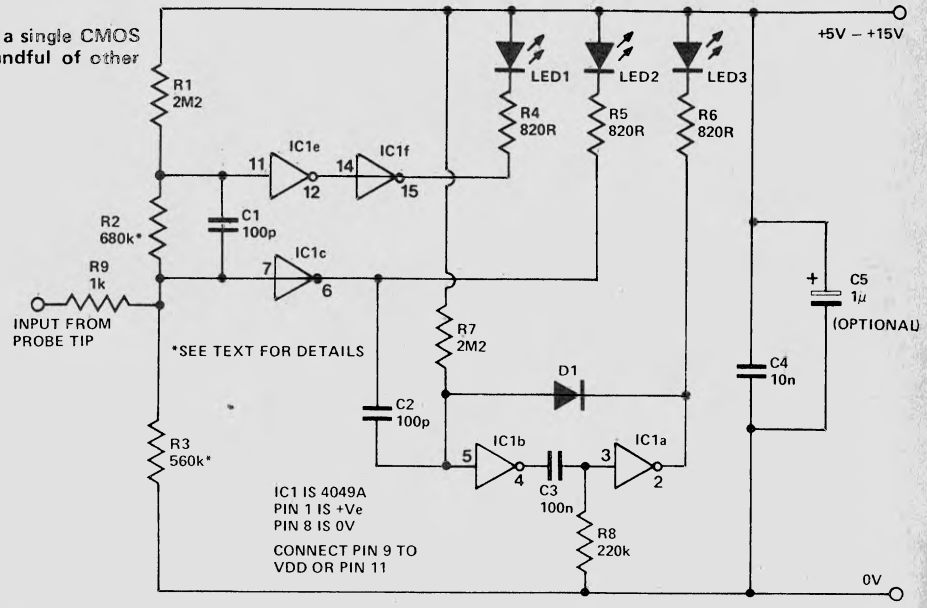
Indication is by means of three LEDs. Two red LEDs indicate either a HIGH or a LOW condition on the point under test, a green LED is used to indicate that a pulse train is occurring.

The circuit uses a single CMOS IC and a handful of resistors and capacitors. The components are mounted on a small pc board and housed in a tubular case such as an aluminium cigar tube or a length of plastic conduit. The power is supplied from the actual circuit under test and the performance characteristics of the prototype are described in the specification listed here. ▶



A logic probe is an invaluable aid for debugging or servicing digital circuitry. This project is inexpensive and easy to build.

The circuit is simple, involves a single CMOS IC, three LEDs and a handful of other components.



SPECIFICATION ETI-148

- TTL or CMOS compatible
- Supply voltage: 5 to 15 volts
- Input impedance: over 400k
- Indicates HIGH (1), LOW (0) or floating states
- Follows high frequency pulse trains – over 1.5 MHz
- Detects single pulses down to 500 nsec in width, and stretches these to 15 msec.
- Relative brightness of HIGH/LOW LEDs indicates duty cycle of pulse trains.

HOW IT WORKS ETI 148

Three of the six inverter/buffers in IC1 are used in the high/low detection circuit. IC1c is connected to the probe tip via R9. When the input goes HIGH (logic 1), IC1c output goes low and illuminates LED 2 through R5. Similarly when the input goes LOW (logic 0), the series pair IC1e and f illuminate LED 1 through R4. The resistor network R1, R2 and R3 ensure that the outputs of both IC1c and IC1f remain high when the input is 'floating'. C1 is connected across R2 as a 'speed-up capacitor' to maintain a sharp pulse shape into IC1e and so improve the ability to follow high frequency pulse trains (over 1MHz)

The two inverters IC1a and b form a monostable circuit that stretches short pulses (less than 500 nsec) out to 15 msec (0.7RC) using C3 and R8. The input of the monostable comes from the output of IC1c and is isolated from the DC level of this output by C2. The combination of R7 and D1 normally holds IC1b input high. When a negative going pulse is fed into IC1b through C2, the output goes high, forcing IC1a to go low and illuminate LED 3. Diode D1 ensures that the input to IC1b is kept low (0.7V above zero) so long as the output of IC1a remains low. This prevents subsequent pulses from re-triggering IC1b until the monostable itself retriggers via discharge of C3 to earth through R8, and allows IC1a output to go high, switching off LED3.

Capacitors C4 and C5 (optional) confer immunity to spikes or pulses in the supply lines, which are taken from the circuit being tested.

Construction

A printed circuit board is recommended for this project to provide consistent performance characteristics.

Before attempting to mount the components on the printed circuit board check to see that it fits easily into the case. The board must be a loose enough fit to allow it to be moved up and down within the case over a range of at least 5 mm. (Refer to the diagram).

If this is not possible, the width of the board can be reduced slightly with a file or coarse sandpaper, taking care not to remove too much or to damage the copper portions of the board.

The other alternative is to use a larger case – buy a bigger cigar! This movement within the case is necessary so that the LEDs can be juggled into position in the holes in the casing (see later).

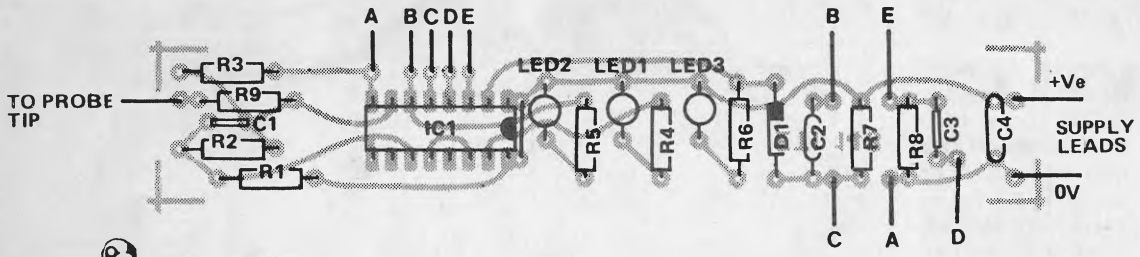
Mount the wire links, the resistors and the capacitors on the pc board, keeping all components as close to the board as possible. Note that C3 is mounted on the underside of the board. Next, install the three LEDs. The height of the LEDs above the pc board must be such that the assembly will slide into the case with the board pushed down against the bottom of the case (see diagram). For a 20 mm diameter case this height should be about 12 mm. If the LEDs are not high enough, then it will not be possible to push the assembled board up into a position where the LEDs project through the holes in the case.

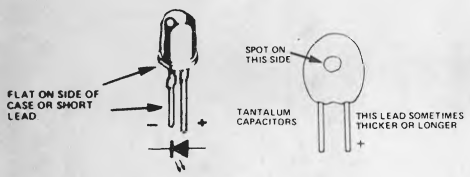
Next, add the power leads (without clips or E-Z hooks at this stage) and the 10 cm wire to the probe tip. Last of all solder IC1 into position, observing all the usual precautions – shorted pins, heat sink, earthed soldering iron, pins 8 and 16 soldered first.

The probe tip housing on my prototype was turned from perspex and a 2 mm hole drilled through the centre. The probe tip wire is soldered to the end of a darning needle which is cemented into the housing with epoxy, allowing the needle to project about 15 mm beyond the end of the housing. It is not necessary to use a perspex cone, turned up as I have it. A flat-faced plug of a suitable material will suffice equally well.

Drill the 3mm holes for the LEDs at 10 mm intervals, starting 75 mm from the front of the case. The hole for the supply leads is drilled in the back of the case and fitted with a small rubber grommet (or plastic LED housing) to prevent the case rubbing through the insulation on the leads.

Before mounting the assembled pc board in the case check the circuit for dry joints, solder bridges, incorrectly mounted components, etc. Then test the device as follows. Connect to a five volt supply and observe the three LEDs. None should light with the probe tip isolated. If the LOW LED (LED 2) comes on or flashes, then R2 is too small and must be replaced by a slightly larger resistor (say 820k). Touching the probe tip with the fingers may cause LED 2 to light, but this should go off when the tip is isolated. Touching the probe tip to either supply rail should light the appropriate LED, with the

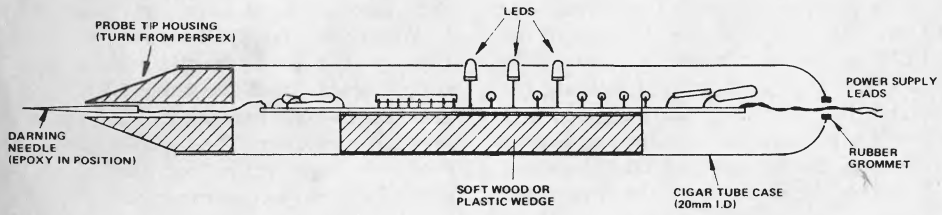


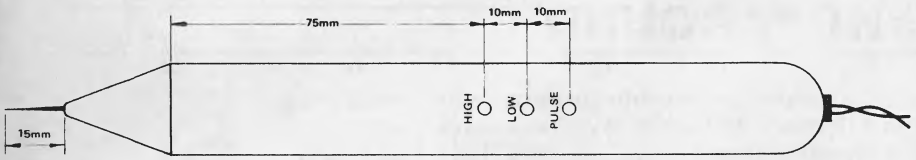


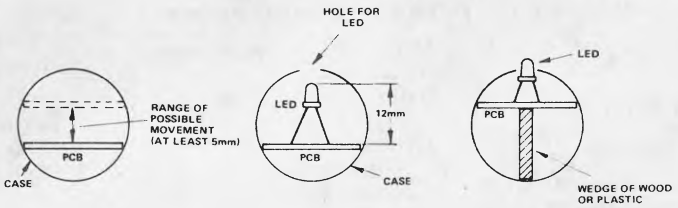
NOTE
C5 IF USED IS MOUNTED ACROSS C4 (OBSERVE POLARITY)

CONNECT RESPECTIVE LETTERS TOGETHER ATO A B TO B etc.

Component overlay for the pc board. Refer to the construction diagrams below for correct assembling of the LEDs.







PARTS LIST – ETI 148

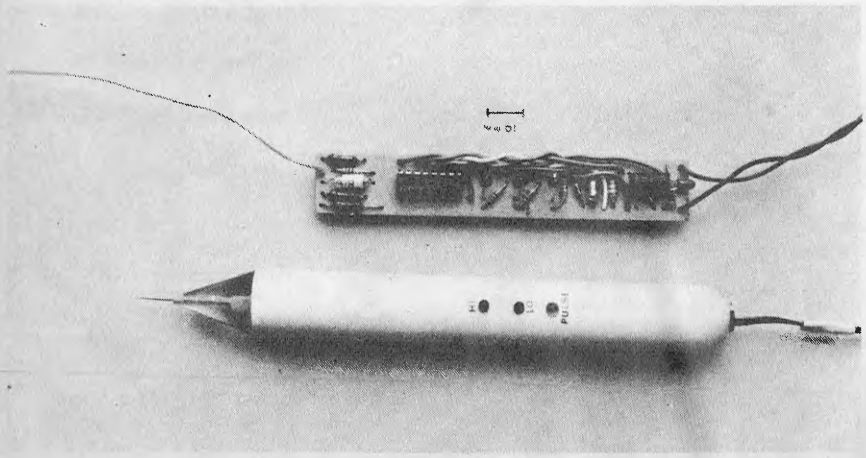
Resistors all ¼W, 5%
R1,7 . . . 2M2
R2 . . . . 680k*
R3 . . . . 560k*
R4,5,6 820R
R8 . . . . 220k
R9 . . . . 1k

Capacitors
C1,2 . . . 100p Ceramic
C3. . . . . 100n Greencap
C4. . . . . 10n Greencap
C5. . . . . 1μ Tantalum (Optional)

Semiconductors
ICI 4049A
LED 1,2 . 3mm red
LED 3 . . 3mm green
D1 . . . . 1N4148 (or equivalent)

Miscellaneous
pcb; red and black leads with alligator clips or E-Z hooks;
cigar case (or equivalent) – minimum dimensions 20mm ID, 140mm long;
perspex rod for probe tip housing;
darning needle.

Resistors R2 and R3 may have to be altered slightly (in the range 470 k to to 1M2) to suit the transfer characteristics of IC1 – see text.



The printed circuit board for this project is reproduced on page 58.

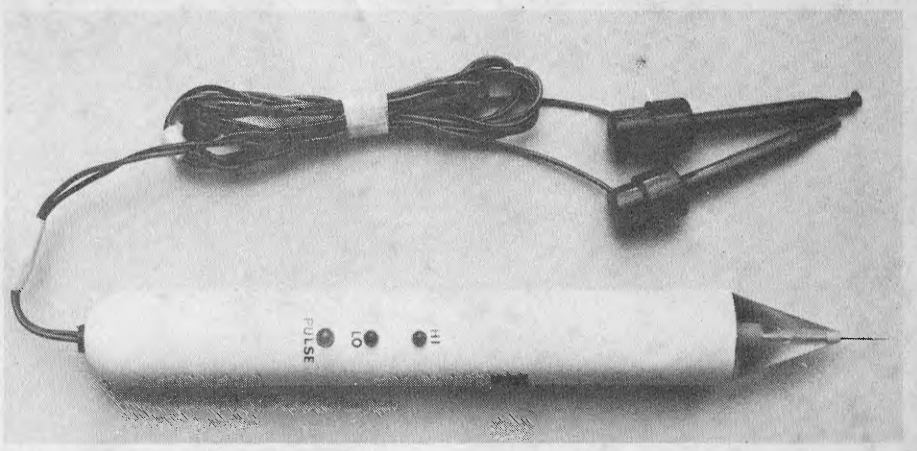
These diagrams above, and the picture left show the general construction of the probe and the drilling of the cigar tube or whatever case is used.

PULSE LED flashing when the tip first touches the positive rail. If the LOW LED does not light when the probe is connected to 0 V, then R2 is too large. Change R2 to 560 k and repeat the sequence above.

Now try a 15 volt supply. Again, all LEDs should be extinguished when the probe tip is isolated. The HIGH LED (LED 1) may glow very faintly. If this glow is too strong, reduce the value of R3 to say 470 k. However, if R3 has to be altered it will be necessary to recheck the circuit at 5 V to see that the low voltage performance is still satisfactory. At 15 volts repeat the process of touching the probe tip to the two supply rails. The results should be the same as in the case of the 5 volt supply, but the LEDs will be considerably brighter.

When satisfied that the circuit works correctly mount it in the case. First, cover the edges of the pc board with strips of tape to insulate it from the case and apply a thin smear of epoxy cement around the base of each LED. Feed the power supply leads through the back of the case, followed by the assembled board. Jockey the board into a position where the LEDs are directly under the holes in the case and then push the assembly up into a position so that the LEDs protrude through the holes in the case. The epoxy around the base of the LEDs will anchor them in position. In addition to this means of holding the board in place, a small wedge of soft wood, plastic or similar insulating material can be inserted into the space between the bottom of the board and the case. The probe tip and its plastic housing is then inserted in the front of the case and epoxied in position.

When the epoxy has set, fit the clips or E-Z hooks to the ends of the supply leads, label the three LEDs and give the whole instrument a coat of protective lacquer. The completed logic probe is now ready for use – but don't forget to smoke the cigar! ●



The completed logic probe.

SHOPAROUND

This page is to assist readers in the continual search for components, kits, printed circuit boards and other parts for ETI projects and circuits. If you are looking for a particular item or project and it is not mentioned here, check with ETI advertisers.

Printed circuit board and panel suppliers

Almost every pc board ever published by ETI may be obtained from the following suppliers:

All Electronic Components
118 Lonsdale St
Melbourne Vic. 3000

RCS Radio
651 Forest Rd
Bexley NSW 2207

Panels, meter scales and dial faces for almost every ETI project published may also be obtained from the above two firms.

For pc boards produced over the past three to five years, the following suppliers generally keep stocks on hand:

Electronic Agencies
115-117 Parramatta Rd
Concord NSW 2137
and
117 York St
Sydney NSW 2000

Radio Despatch Service
869 George St
Sydney NSW 2000

Rod Irving Electronics
125 High St
Northcote Vic.3070

James Phototronics
522 Grange Rd
Fulham Gardens SA5024

Jemal Products
P.O. Box 168
Victoria Park WA 6100

Jactronics
58 Appian Drive
St Albans Vic. 3021

Sunbury Printed Circuits
Lot 14, Factory 3,
McDougall Rd
Sunbury Vic. 3429

Billco Elecronics
Shop 2, 31 Pultney St
Dandenong Vic. 3175

Mini Tech
P.O. Box 9194
Auckland N.Z.

Kits and components

All Electronic Components
118 Lonsdale St
Melbourne Vic. 3000

Altronics
105 Stirling St
Perth WA 6000

George Brown & Co
174 Parramatta Rd
Camperdown NSW 2050

David Reid Electronics
127 York St
Sydney NSW 2000

Electronic Agencies
115-117 Parramatta Rd
Concord NSW 2137
and
117 York St
Sydney NSW 2000

Ellistronics
289 Latrobe St
Melbourne Vic. 3000

Dick Smith Electronics
Mail Order
P.O. Box 321
North Ryde NSW 2113

Jaycar
125 York St
Sydney NSW 2000

Kalextronics
101 Burgundy St
Heidelberg Vic. 3084

Magraths
208 Little Lonsdale St
Melbourne Vic. 3000

Radio Despatch Service
869 George St
Sydney NSW 2000

Radio Parts
562 Spencer St
West Melbourne Vic. 3003

Rod Irving Electronics
425 High St
Northcote Vic. 3070

R&D Electronics
133 Alexander St
Crows Nest NSW 2065
and
257 Burwood Hwy
Burwood Vic. 3125